

UNIVERSITY OF TORONTO
STUDIES

BIOLOGICAL SERIES

No. 37: PUBLICATIONS OF THE ONTARIO FISHERIES
RESEARCH LABORATORY, XLIX.

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T68
no. 49
1934

THE UNIVERSITY OF TORONTO PRESS,
1934

University of Toronto

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Biological Series, No. 37

AN ECOLOGICAL CLASSIFICATION
OF CERTAIN ONTARIO STREAMS

By

WILLIAM E. RICKER

(FROM THE DEPARTMENT OF BIOLOGY
UNIVERSITY OF TORONTO)

PUBLICATIONS OF THE
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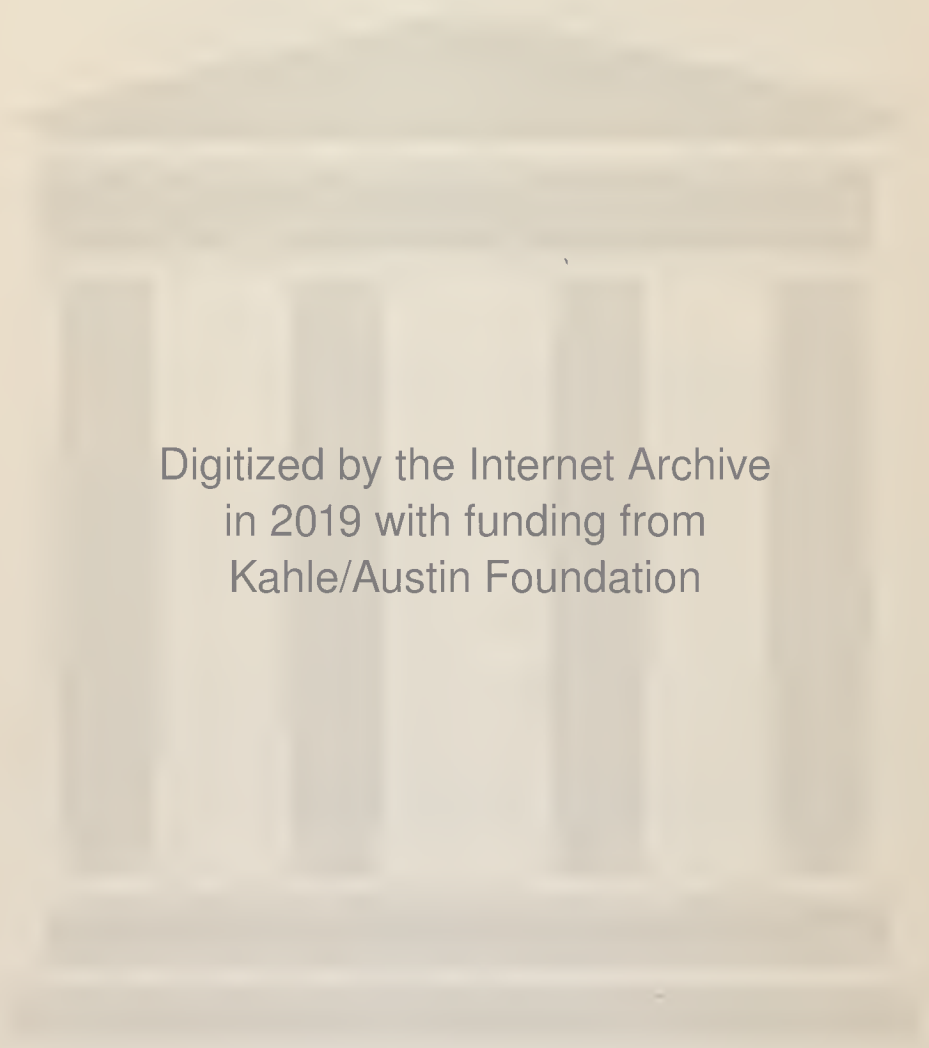
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TORONTO
THE UNIVERSITY OF TORONTO PRESS
1934

QH 1.T68, no 49, '934

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AN ECOLOGICAL CLASSIFICATION OF CERTAIN ONTARIO STREAMS

ABSTRACT

The standard methods of limnological investigation, which had previously been used, in Ontario, upon lakes almost exclusively, have been applied, with suitable modifications, to a study of streams in this province. It appears that the various organic and inorganic peculiarities of flowing waters may be correlated to a degree sufficient to allow of a useful, if rather arbitrary, classification being made. The features utilized in this way are of three kinds: (1) physical—character of the watershed; width, depth, and kind of bottom of the stream, temperature and rate of flow of the water; (2) chemical—kinds and quantities of gases and solids dissolved in the water; (3) biotic—kinds and numbers of plants and animals which are members of the stream community.

Such a classification is proposed in this paper, and the peculiarities of the streams of each division discussed in greater or less detail, with especial reference to the food relationships of game fish. Most attention has been given to streams cool enough to contain speckled trout (*Salvelinus fontinalis*), and particularly to one slow hard-water trout stream, the Mad river.

Economically, these studies should be of value to fish-culturists, as indicating what features may most profitably be included in their necessarily rapid "planting surveys", and as an aid in placing a stream in its proper category when only limited data are available.

INTRODUCTION

In the past two decades many biologists have been occupied in a study of the ecological relationships in which the fauna and flora of lakes are involved. To-day, not only is there available a large amount of detailed information on these bodies of water, but various methods of classification have been proposed which are, in their broader features at least, apparently of general application throughout the north temperate region. In comparison with this intensive study of lakes, rivers have been almost uniformly neglected. With a few exceptions, such ecological data as are at hand consist of notes made incidental to systematic studies, or of the very general observations made in connection with fish-planting surveys. The reason for this discrimination is probably to be found in the overwhelming variety of habitats

presented in streams and rivers, the inadequate systematic treatment of their fauna, and the lesser economic importance of their fish.

Important information upon the general ecology of certain streams in which speckled trout live is to be found in publications by Hankinson (1922) and Kendall and Dence (1927). A study of the physical and biotic peculiarities of mountain streams has been made by Steinmann (1907) and Thienemann (1912) in Europe, and by Dodds and Hisaw (1924a, 1924b, 1925) and Muttkowski (1929) in America. A number of authors have concerned themselves with the physical and chemical characteristics of the waters of American streams: Belding (1928), Butcher *et al.* (1927), Coker (1925), Cowles and Schwitalla (1923), Creaser (1930), Faigenbaum (1930), Gutsell (1929), Powers (1928, 1929), Shelford (1925), and Wagner (1926, 1927, 1928). Publications dealing with the invertebrate fauna are numerous but widely scattered, are usually purely systematic, and generally deal with only one species or group of species. The papers of Clemens (1917), Leathers (1921), Muttkowski and Smith (1929), Needham and Christenson (1927), and some others have given an account of the place of certain aquatic insects in the life of a river.

In 1930-1, the author endeavoured to obtain information on all of the above points from a single stream habitat—a short section of the Mad river—so that an attempt could be made at discussing the relationships of flora and fauna to each other, and to the physical and chemical peculiarities of the water. During the course of this investigation the possibility suggested itself of extending to streams generally the systematic ecological treatment which lakes have already received.

APPARATUS AND METHODS

I. Water

Rate of flow was determined by finding the length of time in which a floating stick was carried a measured distance by the current.

Volume of flow was calculated from the rate plus the measured width and average depth of the section; no correction was made for "bottom drag".

Temperature was taken by means of a Tycos armoured centigrade thermometer, marked off in degrees and accurate to one-fifth of a degree. Unless otherwise stated, readings were taken three inches below the surface. On the Mad river a Negretti and Zambra continuous recording thermometer was also used. Its graph (figure 4) gives the temperature in degrees Fahrenheit. It was checked by a Negretti and Zambra standardized Fahrenheit thermometer. Owing to pointer drag, the recording thermometer registered 0.5° F. too low when the temperature was near a maximum, the same amount too high when approaching a minimum, and various lesser amounts elsewhere. It was impossible to correct for these variations. Correction has been made for a constant error: $+1.2^{\circ}$ F. in 1930, and $+3.8^{\circ}$ F. in 1931.

Air temperature was recorded by means of a maximum and minimum thermometer, accurate to one-half of a degree Fahrenheit; it was mounted near the river, in the shade of a thicket, five feet above the ground.

Oxygen content of the water was determined by a modification of Miller's method, using ferrous-ammonium sulphate for titration. The solutions were standardized by reference to Roscoe and Lunt's table of saturation values (Sutton, 1924, in appendix). Distilled water was saturated with atmospheric oxygen at 18° C., in the fashion described by Sutton. This standard solution was considered to be 100 per cent. saturated, its oxygen content, determined by titration, was compared with the figure given by Roscoe and Lunt (allowance being made for atmospheric pressure, as below), and a corrective factor found for each sulphate solution. In some of the earlier work this standardization was not done in the laboratory, so samples of water taken in the field, at the foot of a long series of rapids and falls, were considered to be 100 per cent. saturated, and the factor calculated from them.

All tables of saturation values are for an atmospheric

pressure of 760 mm. (29.92 inches) of mercury. These must be corrected to give the value at the pressure prevailing when the determination was made. Pressure varies with the altitude of the station where work is done, and also varies daily according to weather conditions. In lieu of a barometer the author has used the following formula to obtain actual pressure; it is derived from one given by Geddes (1921, p. 110):

$$\log p = \log p_0 - 0.00001570 H$$

where p = pressure at elevation H feet, and p_0 = pressure referred to sea-level, obtained from the daily weather bulletins issued by the Dominion Meteorological Service.

The elevation of most stations may be found in White (1925). The above formula is accurate at 15° C. air temperature. A deviation of 10° C. produces an error of only 0.2 per cent. at 1,500 feet altitude. For more accurate work, or at high altitudes, the following formula may be used:

$$\log p = \log p_0 - 0.00453 \frac{H}{T}$$

where p , p_0 , and H are as above, and T = absolute temperature of the air at elevation H feet. In the present work, corrections for atmospheric pressure have amounted to from two per cent. to six per cent.

Reference to Whipple and Whipple's table (Standard methods of water analysis, 1925, p. 62) shows that the lessening of solubility of oxygen because of salts dissolved in the water may be neglected in fresh waters which contain less than 250 parts per million of solids in solution.

Hydrogen-ion concentration has been measured using a La Motte colorimetric comparator, with bromthymol blue, phenol red, and thymol blue indicators. In hard waters, which contain much bicarbonate, these appear to be satisfactory; but in soft water it would seem that the pH of the indicator used (which is one-tenth of the volume of the water used) has a significant effect upon the pH of the resulting mixture. For example, the Oxtongue river had a bicarbonate content of less than ten parts per million, expressed as CaCO_3 . On July 18, 1930, the pH reading was

6.2, using the usual amount of indicator. When only half of this amount was used, the intensity of the colour was, of course, reduced, but its hue also changed, and indicated a pH of about 6.6. However, pH readings from soft waters, even if not accurate absolutely, are comparable among themselves.

Determinations of free carbon dioxide (CO_2) and bi-carbonate (HCO_3) were made by titrating with N/50 sodium carbonate and N/50 sulphuric acid, using phenol phthalein and methyl orange respectively, as outlined in Rept. Ont. Board of Health (1919). Hardness was tested by means of a standard soap solution. The author is indebted to Mr. E. S. Pentland for many determinations of the chemical composition of the water.

II. Invertebrates

Samples of the upper seven cm. of a river bed were taken by means of a dip net $14\frac{1}{2}$ inches (36.7 cm.) in diameter. The bag, through which the water and mud were strained, was of marquisette, having 24 threads to an inch (9.4 per cm.). After taking a dredging, the area of the hole left on the bottom was measured, with a possible error of about ten per cent. For a few of the deeper water collections, an Eckman dredge having a gape of 77.5 square inches (500 square cm.) was used; the constant clogging of the jaws and the inconvenience of operating it from a canoe limited its usefulness. After a dredging was washed in the net, the living animals were carefully picked out of the weeds, sand, or debris which remained, and preserved in 70 to 80 per cent. alcohol. The larger and rarer invertebrates, such as *Benacus* or *Helisoma*, were often taken individually as they were seen. Imagos of aquatic insects were collected by means of a net, or from under leaves of trees.

In this paper four words denoting frequency of occurrence have been applied to the invertebrates of the stream bottom with the following arbitrary values:

More than 15 per square foot (=0.0929 square metre):	Abundant
6 to 15 per square foot (=0.0929 square metre):	Frequent
2 to 5 per square foot (=0.0929 square metre):	Occasional
Fewer than 2 per square foot (=0.0929 square metre):	Rare

III. Fish

Sculpins, sticklebacks, and trout less than one and a half inches long were often taken in a dip net. A ten-foot minnow seine was used to capture slightly larger trout and many other fish. Large trout, creek chub, shiners, *etc.*, were most often taken by angling, with either worm or fly as bait.

The length of a fish was measured in inches from tip of snout to fork of tail. Girth was measured immediately in front of the dorsal fin. Weight of fish heavier than one ounce (28.4 grammes) was measured by means of a postal scale which was accurate to the nearest tenth of an ounce. Lighter fish were weighed on a balance accurate to 0.01 grammes. With a few exceptions, fish more than six inches (15.2 cm.) long were measured and weighed soon after they were caught and while they were still fresh; fish less than that length were measured about seven months later, after being preserved in formalin and alcohol.

IV. Stomach analysis

The contents of the fish stomachs were analysed singly. The total volume of the contents of each stomach was found by displacement of alcohol or water in a graduate. Items were then sorted and counted and the percentage of the whole which each group formed was estimated. From this the actual volume of each kind of food in each stomach was obtained. Averages for a series of specimens were obtained by adding together these volumes, then calculating its percentage of the total volume of all the stomachs.

When only a few large items occurred in a stomach, their several volumes were often found separately, by displacement. In the case of very small fish, the total volume, as well as the percentages, was estimated.

CLASSIFICATION OF ONTARIO STREAMS

The factors to be considered in making a classification of streams are to a great extent interdependent, and are

consequently difficult to evaluate. The following is a list of the more important:

A. Chemical composition of the basic rocks and of the soil of the region through which the river flows, which determines the bicarbonate content and hardness of the water and with carbon dioxide content, its hydrogen-ion concentration. The waters of Ontario rivers are rather sharply divided into "soft or brown waters" and "hard or clear waters" corresponding roughly to the division of the province into a region of igneous rocks (including most of the pre-Cambrian shield) and regions of sedimentary rocks (mostly of Ordovician, Silurian, or Devonian age).

B. Type of soil and vegetation of the watershed, which are the principal factors in determining the turbidity of the water.

C. Speed of current, which may be divided into (1) slow—less than 1.5 feet (0.46 metre) per second, and (2) fast—more than 1.5 feet per second.

D. Type of bottom: Vegetable debris, mud, sand, gravel, stones, boulders, bedrock, or hardpan.

E. Temperature of the water.

F. Width and depth, which with C determine volume of flow.

G. Flora, which is determined by A, C, D, E, and probably F and H.

H. Fauna, which is determined by C, D, E, F, G, by geographical position, and by the presence of barriers to migration.

I. Oxygen and carbon dioxide content of the water, which are influenced by almost all of the above factors.

Carpenter (1928) has proposed a classification of the streams of Great Britain, on the basis of some of these factors. It is, however, incomplete in some respects when applied to Ontario waters, and includes some types which have no exact equivalent here. Shelford and Eddy (1929) and Needham and Lloyd (1930) have given some considera-

tion to differences between various American streams, chiefly as regards their fauna, but they too omit many Ontario types. It has seemed better, therefore, to make a preliminary grouping of Ontario streams into natural, though intergrading, classes, without direct reference to previous work:

A. Creeks. Volume of flow less than ten cubic feet (0.28 cubic metre) per second on June 1; width less than ten feet (3.0 metres).

1. Spring creeks. Permanent, usually spring fed; maximum summer temperature lower than 20° C.

a. Stony bottom, moderate to rapid current, vegetation of aquatic mosses.

b. Sandy bottom, moderate to rapid current, bare of vegetation.

c. Mud bottom, slow current, vegetation usually water-cress, or none.

d. Bottom of dead leaves and other vegetable debris, slow current, vegetation of mosses or none.

2. Drainage creeks. Not spring fed, or far from springs, often completely dry in summer; maximum summer temperature above 20° C., usually much higher.

B. Rivers. Volume greater than ten cubic feet (0.28 cubic metre) per second on June 1; width greater than ten feet (3.0 metres).

1. Trout streams. Maximum summer temperature not in excess of 24° C.; principal piscivorous fish, *Salvelinus fontinalis*.

a. Slow trout streams. Mud over most of bottom; slow current; vegetation of *Nymphaea*, several species of *Potamogeton*, etc.

(i) Slow hard waters. Bicarbonate content greater than 100 parts per million (expressed as CaCO_3), hardness more than 150 parts per million; vegetation including *Chara*, but not

Brasenia or *Castalia*; volume of flow on June 1 not greater than 100 cubic feet (2.8 cubic metres) per second.

- (ii) Slow soft waters. Bicarbonate content less than 25 parts per million (expressed as CaCO_3), hardness less than 50 parts per million; vegetation including *Brasenia* or *Castalia*, never *Chara*; volume on June 1 up to 500 cubic feet (14 cubic metres) per second.

b. Swift trout streams. Stony bottom; moderate to rapid current; vegetation of *Cladophora* or aquatic mosses; typical invertebrates Hydropsychidae, Heptagenidae, Simuliidae.

- (i) Swift hard waters. Bicarbonate content greater than 100 parts per million (expressed as CaCO_3), hardness more than 150 parts per million; *Simulium* larvae merely frequent; volume of flow on June 1 not greater than 150 cubic feet (4.2 cubic metres) per second.

- (ii) Swift soft water. Bicarbonate content less than 25 parts per million, hardness less than 50 parts per million; *Simulium* larvae extremely abundant; volume of flow on June 1 up to 500 cubic feet (14 cubic metres) per second.

2. Warm rivers. Maximum summer temperature in excess of $24^\circ \text{C}.$; volume of flow with no upper limit; principal piscivorous fish of the families Centrarchidae and Esocidae.

a. Stony bottom, moderate to swift current, supporting typically a *Cladophora*-Hydropsychidae-Etheostominae association (Shelford and Eddy, 1929).

b. Mud bottom, slow current; with a very varied biota, including *Nymphaea*, Unionidae, Catostomidae, and many Cyprinidae.

The distinctions between swift-stony and slow-muddy types are, perhaps, the most fundamental, from the point of view of the biota, of any which were used in preparing the table. They have been relegated to the third rank for the sake of convenience, because swift and sluggish reaches often alternate along the course of a single stream.

The "warm rivers" are entitled to much greater subdivision than that shown, but almost no information is available which treats of Ontario examples.

The author has visited every kind of stream mentioned, but the amount of attention which each has received has by no means been uniform—varying from a single casual examination to a prolonged period of careful study. The Mad river has been most favoured, and the description of its various aspects will constitute the bulk of this paper. Nevertheless, each type will be discussed in its turn, following the order given in the above outline.

STONY SPRING CREEKS

"B" creek, one of the tributaries of Little Wonder pond, at Horning's Mills, Ontario, is in its upper reaches a typical stony spring stream. It rises from several springs in a small cedar copse, flows out into a small pool in an old farmyard, then through an open stony channel 200 feet (60 metres) long, which is the typical "upper section" of this description. Leaving the farmyard it enters a wood, mostly of evergreens, flows for about 300 yards (270 metres), and is joined by a larger creek which had its origin in springs about a mile (1.6 km.) above. The combined streams flow out into a grassy glade beset with scattered elms and poplars. Here the current again quickens and enters the typical "lower section", distinguished from the upper by a higher and more variable temperature and a greater volume of flow. The two sections are compared in table 1. On July 24 there was a temperature difference between the two of 5.4° C. The highest temperature recorded during the season was 18.5° C. at 3.00 p.m. on July 9—a very hot day; it seems probable

TABLE 1. Physical and chemical features of a spring creek (B creek)

Place	Date 1928	Time	Average width (feet)	Average depth (feet)	Rate of flow (ft. per sec.)	Vol. of flow (cu. ft. per sec.)	Temp. °C.	pH.	Oxygen		
									cc/l.	p.p.m.	Per cent. sat.
Springs	July 24	3.30 p.m.	...	...	...	...	7.3	7.4	6.3	9.0	81
Upper section ...	July 24	3.30 p.m.	4	0.4	1.3*	2*	10.4	7.6	7.4	12.2	100
Lower section ...	July 24	3.30 p.m.	10	0.6	1.3	7	15.8	8.0	6.5	10.7	99

*Estimated values.

that the absolute maximum would not exceed 20° C. The pH was less in the upper section than in the lower, and the oxygen content greater, though the water of both reaches had reached saturation in this respect. Both were rich in lime and carbonates, to an extent of 150 to 200 parts per million. The volume of flow of the upper section was nearly constant throughout the summer; that of the lower increased to double its normal value after a heavy rain. On such occasions the water became rather turbid. Both sections had a moderately rapid current, and a bottom of gravel or small stones.

Aquatic vegetation in the stony sections of B creek consisted only of lithophilous and clinging algae, and mosses such as *Fissidens*, *Fontinalis*, and *Hygrohypnum*.

Several collections of aquatic invertebrates were made in the stream. Characteristic organisms were the stonefly *Nemoura* and the caddis *Hesperophylax designatus*. Both of these are more abundant in the cold upper section than in the warmer stretch below, and are absent or rare in larger streams. In the following rather incomplete list, the letter U indicates that the organism in question was found in the upper section; L, in the lower section of the creek.

Turbellaria

Planaria. L, occasional.

Oligochaeta

Lumbriculidae. U, rare.

Hirudinea

Glossiphonia complanata. U, occasional.

Nephelopsis obscura. U, rare.

Ephemeroptera

Leptophlebia. L, frequent.

Ephemerella spp. L, frequent.

Baetis spp. L, abundant.

Iron pleuralis. U, frequent; L, occasional.

Plecoptera

Chloroperla. U, frequent.

Alloperla? L, occasional.

Leuctra. U and L, occasional.

Nemoura sp. (with gills at neck). U, frequent; L, occasional.

Nemoura sp. (gill-less). U, frequent.

Trichoptera

Rhyacophila fuscula. L, occasional.

Mystrophora americana. L, frequent.

Hydropsychidae. U, occasional; L, frequent.

Philopotamus. L, abundant, in moss.

Stenophylax scabripennis. L, rare, in slower pools.

Neophylax, cf. *autumnus*. L, occasional.

Hesperophylax designatus. U, abundant; L, occasional.

Larvae, prepupae, pupae and imago were taken on June 7. On September 7 young larvae were common.

Diptera

Chironominae. U and L, frequent.

Tanypinae. U and L, occasional.

Simulium. L, frequent.

Coleoptera

Helmis. L, occasional.

Gastropoda

Gyraulus, cf. *parvus*. U, rare.

Physella. U, rare; L, occasional.

Fish. Three species of fish were found in B creek:

Cottus cognatus. Rare. One specimen was taken 50 feet from the head of the creek.

Eucalia inconstans. Rare in side pools of the lower section.

Salvelinus fontinalis. Fingerling speckled trout were abundant in both the upper and lower gravel sections, and fairly common in the slower intermediate reaches. Adults were not seen in the shallow exposed rapids, but were common in a few deep sheltered pools.

A few small trout were obtained for study, and the analysis of their stomachs is presented in table 2. In early June the fingerlings were not yet large enough to utilize any

part of the rich invertebrate fauna except the Chironomid larvae and pupae, and a few other small insects. By August 1 their percentage consumption of midges had been reduced by one-half, and the gap was filled by mayflies, caddis, beetles, and terrestrial insects. Three yearling trout taken at the same time consumed a mixture of insects, chiefly caddis larvae.

TABLE 2. Food of speckled trout in B creek

	Upper section	Lower section	Upper section	Inter-mediate section
Date taken	June 7	June 7	August 1-2	August 1-2
Number of stomachs examined..	4	1	9	3
Average length in inches.....	1.36	1.84	2.28	4.83
Variation in length.....	1.25-1.50	—	2.06-2.69	3.62-5.44
Average volume of contents in cubic mm.....	16	19	71	290
Average number of Nematoda..	0	0	+	3
Vegetable matter.....	—	—	+	5
Aquatic Insecta				
Ephemeroptera: Baetidae....	—	—	19	5
Plecoptera.....	—	37	5	2
Trichoptera: Larvae and pupae*.....	—	—	11	35
Cases.....	—	—	—	9
Heteroptera: Corixidae.....	—	—	+	2
Diptera: Chironomidae.....	94	16	47	8
Simuliidae.....	—	—	2	8
Others.....	6	37	2	1
Coleoptera.....	—	—	8	8
Terrestrial Insecta**.....	—	10	6	14
Total surface food.....	0	10	18	19
Total bottom food.....	100	90	82	81

*Includes Polycentropidae, Hydropsychidae, *Hesperophylax designatus*, and other Limnephilidae.

**Includes Thysanura, Homoptera, Diptera, Coleoptera.

Note: In this and all subsequent tables of stomach contents, a figure indicates what per cent. of the total volume of contents is made up of the item in question, a cross (+) shows that the item comprised less than one-half of one per cent. of the total, a dash (—) that it was entirely lacking.

SANDY SPRING CREEKS

Tally-Ho creek, flowing into Peninsula lake, near Huntsville, Ontario, is typical of this class. It is a soft-water

stream, rising from springs in a wooded valley and flowing out into a swampy meadow. Its average width is three feet (1 metre), and volume of flow 1.1 cubic feet (0.031 cubic metre) per second in May. A water analysis, made at 10.00 a.m. on May 27, 1930, was as follows: temperature 7.0° C., pH less than 6.8, oxygen content 7.8 cc. per litre, 11.2 parts per million and 100 per cent. saturated, acid carbonate (HCO_3) 12 p.p.m. expressed as CaCO_3 , free carbon dioxide 1.3 p.p.m. In summer, the volume decreases to 0.8 cubic feet (0.023 cubic metres) per second, and the temperature rises to about 20° C. on hot days.

In the sandy beds which constitute most of the bottom of the stream, the author was unable to detect any life whatever. The trout in these places must eat either terrestrial organisms, or the insects which cling to logs, *etc.*, in the water, or insects washed down from a stony bottom.

The fish observed in this stream were the speckled trout, and, in the lower reaches, the creek chub (*Semotilus atromaculatus*). None of the trout seen was over seven inches (18 cm.) long, although longer specimens are said to have been captured.

Small cold creeks with sandy bottom are not as common in southern as in northern Ontario, but, when they occur, they seem to be equally deficient in living organisms. Evidently the carbonate content of the water is not an important factor in determining the dearth of life. It is interesting to note that the same condition is prevalent in lakes. For example, Rawson (1930) has shown that in lake Simcoe sandy beaches are much less productive than those with stony, muddy, or weed-covered bottom.

MUD-BOTTOM SPRING CREEKS

Dogwood creek, a tributary of the Mad river in Grey county, Ontario, rises from springs, and for most of its course flows with gentle current through an evergreen swamp. When it emerges from the tall timber, its channel, low hung with *Myrica Gale*, meanders through a swale of

small willows (*Salix* sp.) and *Cornus stolonifera* until it meets the larger trout stream (figure 2). At this point its average width is about five feet (1.5 metres), and depth two feet (0.6 metre). In early summer its volume of flow was 4.6 cubic feet (0.13 cubic metre) per second; in August this was reduced to 2.0 cubic feet (0.057 cubic metre) per second which low level it maintained up to the end of the following March. Soon after, the spring floods filled the channel and submerged the surrounding land to a depth of two feet; the flow on April 20 was 30 cubic feet (0.85 cubic metre) per second.

One effect of spring water on streams is to steady their temperature; they remain cooler in summer and warmer in winter than do rivers which lack its ameliorating influence. The highest figure recorded in Dogwood creek was 16.0° C., at 4.00 p.m. on a hot afternoon in July; the lowest was 2.2° C. at 10.15 a.m. on October 20. The oxygen content of the water (taken during the day) hovered near 90 per cent. of saturation throughout the year; the pH was between 7.7 and 7.8, except at flood time, when it dropped to 7.3. Its water was normally rich in lime and carbonates. Complete data on water conditions are presented in table 3.

The bottom of Dogwood creek was of rather firm mud in the channel, and softer silt along the borders. About half of this remained bare throughout the year; the remainder became grown up with *Radicula Nasturtium-aquaticum*, *Ranunculus circonatus?*, and a species of *Sparganium* with trailing submerged leaves. The first of these was most abundant and most characteristic; it preferred a rather slower current than the other two.

Collections of the invertebrate fauna were made throughout the year, on a mud bottom only, at a depth of one foot (0.3 metre). Analysis of these dredgings has revealed a very characteristic association, which is not only entirely different from that of stony or sandy creeks, but also bears little specific resemblance to the mud banks of the adjacent, but warmer, Mad river.

TABLE 3. Water characteristics of Dogwood creek

Date	Time	Current speed (feet per second)	Volume of flow (cubic feet per second)	Temperature		pH.	Oxygen		
				°C.	°F.		cc/l.	p.p.m.	Per cent. sat.
May 22, 1930.....	3.00 p.m.	0.8	4.6	16.5	61.5	7.8	5.5	7.8	86
June 17, 1930.....	12.15 p.m.	1.0	4.6	13.7	57.	...	6.1	8.7	91
July 7, 1930.....	4.00 p.m.	...	...	16.0	61.	...	6.0	8.6	92
August 16, 1930.....	3.30 p.m.	0.7	2.0	15.0	59.	...	6.5	9.3	98
September 4, 1930....	5.15 p.m.	...	...	12.9	55.	7.7	6.3	9.0	90
October 20, 1930.....	10.15 a.m.	...	...	2.2	36.	7.8	8.7	12.4	96
March 22, 1931.....	4.45 p.m.	...	1.5?	3.7	38.5	7.7	7.5	10.7	92
April 20, 1931.....	2.50 p.m.	0.8	31.	13.0	55.5	7.3	5.8	8.3	88

Oligochaeta

Tubificidae. Frequent.

Hirudinea

Glossiphonia complanata. Occasional.

Haemopsis plumbeus. Rare.

Nephelopsis obscura. Rare.

Crustacea

Hyalella knickerbockerii. Abundant.

Ephemeroptera

Hexagenia. Rare.

Ephemerella temporalis. Rare.

Leptophlebia. Occasional.

Plecoptera

Leuctra. Rare.

Nemoura. Rare.

Trichoptera

Limnephilus. Rare.

Halesus guttifer. Rare.

Unknown *Limnephilid*. Occasional.

Diptera

Simulium. Rare.

Chironomidae (det. Johannsen)

Procladius (group *adumbratus*). Occasional.

Pentaneuria (*Ablabesymia*) (group *flavifrons*).

Occasional.

Cryptochironomus. Occasional.

Others. Occasional.

Culicoides. Occasional.

Chrysops. Rare.

Coleoptera

Hydroporus depressus. Rare.

Pelecypoda (det. Sterki)

Pisidium overi. Frequent.

Pisidium variabile. Occasional.

Pisidium cf. *sargenti*. Occasional.

Pisidium cf. *milius*. Occasional.

Gastropoda

Physella integra. Frequent (det. Clench)

Valvata sp. cf. *sincera*. Abundant.

The fish found were: *Salvelinus fontinalis*, *Cottus bairdii*, *Eucalia inconstans*, and a small minnow. Only trout were common. The specimens seen were chiefly fingerlings, which early in the year frequented the very shallow borders, often resting on the bottom. A few yearlings and two-year-olds were captured, but they were not very common. In the fall the stream is frequented by adult trout, journeying to the springs above.

The food of some of the fingerlings is listed in table 4. A small creek of this sort produces large quantities of the preferred food of the smallest trout—Entomostraca and Chironomid larvae—but its supply of medium-sized aquatic insects (such as *Baetis*) is less generous. Hence in mid-summer, many of the fingerlings desert the creek for the river below where mayfly nymphs, *etc.*, are commoner. Those which remain feed to a great extent at the surface of the water, taking a variety of terrestrial insects. Many of the common invertebrates of the stream, *e.g.*, *Oligochaetes*, leeches, most caddis larvae, *Pisidium*, *Physella*, and *Valvata*, are unavailable to small trout, by reason either of their large size or of their secretive habits.

HUMUS-BOTTOM SPRING CREEKS

When a spring creek flows with a gentle current through a deciduous forest, dead leaves accumulate on the bottom, and with other decaying vegetable materials, form a rich bed of humus. The invertebrate population of such creeks is often very great in numbers, though not especially varied. Needham and Lloyd (1930, p. 36) describe such streams as they are found near Ithaca, N.Y.: their fauna consists, in the typical leaf beds, of *Tipula abdominalis*, *Nemoura*, *Baetis*, *Leptophlebia*, and *Gammarus*, and on the more open silty bottom of the large caddis *Halesus guttifer*, *Sphaerium*, *Cordulegaster*, *Boyeria*, Gerridae, burrowing mayflies, and “a considerable variety of the lesser midges”.

“Sahara” creek, one mile north of Oliphant beach, Bruce county, Ontario, is of this type. The country in which

it rises consists of sand dunes mostly covered by a thick growth of beech and sugar maple. When examined on July 12, 1930, its volume of flow was 1.5 cubic feet (0.042 cubic metre) per second, and temperature 11.3°C. at 9.10 a.m. Its average width was four feet (1.2 metres), and depth eight

TABLE 4. Food of fingerling trout in Dogwood creek

	May 22, 1930	July 25, 1930
Number of specimens examined.....	10	3
Average length in inches.....	1.14	2.29
Variation in length.....	1.00-1.30	2.00-2.50
Average volume of contents in cubic mm.....	4.8	35.
Average number of Nematoda.....	0	+
Vegetable matter.....	—	3
Entomostraca		
<i>Cyclops</i>	5	—
<i>Canthacampylus</i>	18	—
Ostracoda.....	4	—
<i>Hyalella knickerbockerii</i>	4	—
Aquatic Insecta		
Nymphs of Plecoptera.....	—	5
Larvae of Trichoptera.....	—	8
Simuliidae.....	3	—
Larvae and pupae of Culicidae.....	11	—
Larvae and pupae of Chironominae.....	35	15
Larvae of Tanypinae and <i>Culicoides</i>	12	—
Adult Coleoptera (<i>Hydroporus</i>).....	—	31
Terrestrial Insecta		
Homoptera.....	—	4
Lepidoptera.....	—	2
Diptera.....	+	23
Coleoptera.....	—	4
Hymenoptera.....	—	5
Total surface food.....	3	38
Total submersed food.....	97	62

inches (20 cm.). The bottom was of sand covered by a light layer of silt with many leaves, sticks, bits of bark, etc., and with logs frequently blocking the channel. The fauna was found to include an abundance of *Gammarus limnaeus*, *Pisidium idahoense* (det. Sterki), and Limnephilid larvae (not *Halesus guttifer*, however). Chironomid larvae and

Physella were occasional, *Limnephilus*, a Hydrophilid beetle, and a big *Tipula* rare. No fish were seen in the stream.

DRAINAGE CREEKS

Because of their high temperature and irregular water supply, drainage creeks are not suitable for most fish, and have not been studied.

SLOW HARD-WATER TROUT STREAMS: THE MAD RIVER

Streams of this type appear to be rare in Ontario, because in most regions of calcareous sedimentary rocks, the land has been cleared of vegetation to such an extent that any large slow stream is hot enough to be classed among the "warm rivers". The one example studied by the author—the Mad river—is a rather famous trout stream.

I. Physiography

The Mad river is situated in Gray and Simcoe counties, Ontario, in longitude 80° 15' W. and latitude 44° 20' N. Its total length from the source to its confluence with the Nottawasaga river is about 40 miles (64 km.). Rising in an ever-green swamp a mile north-east of Badjeros, it flows north and east seven miles (11 km.) to Singhampton; turning south-east it runs for seven miles, and is joined by the Noisy river, an important tributary of nearly equal volume. The combined streams continue south and east, passing through Creemore, then turning northward to join the Nottawasaga river 20 miles (32 km.) from the point where the latter stream empties into Georgian bay.

The section here studied is in the upper reaches of the river, six miles (10 km.) from its source. It is one and one-half miles (2.4 km.) long, extending from a point on the gravel road a mile south and west of Singhampton, down to the glen half a mile east of that town. At its lower end is a mill dam, which has flooded the banks for some distance

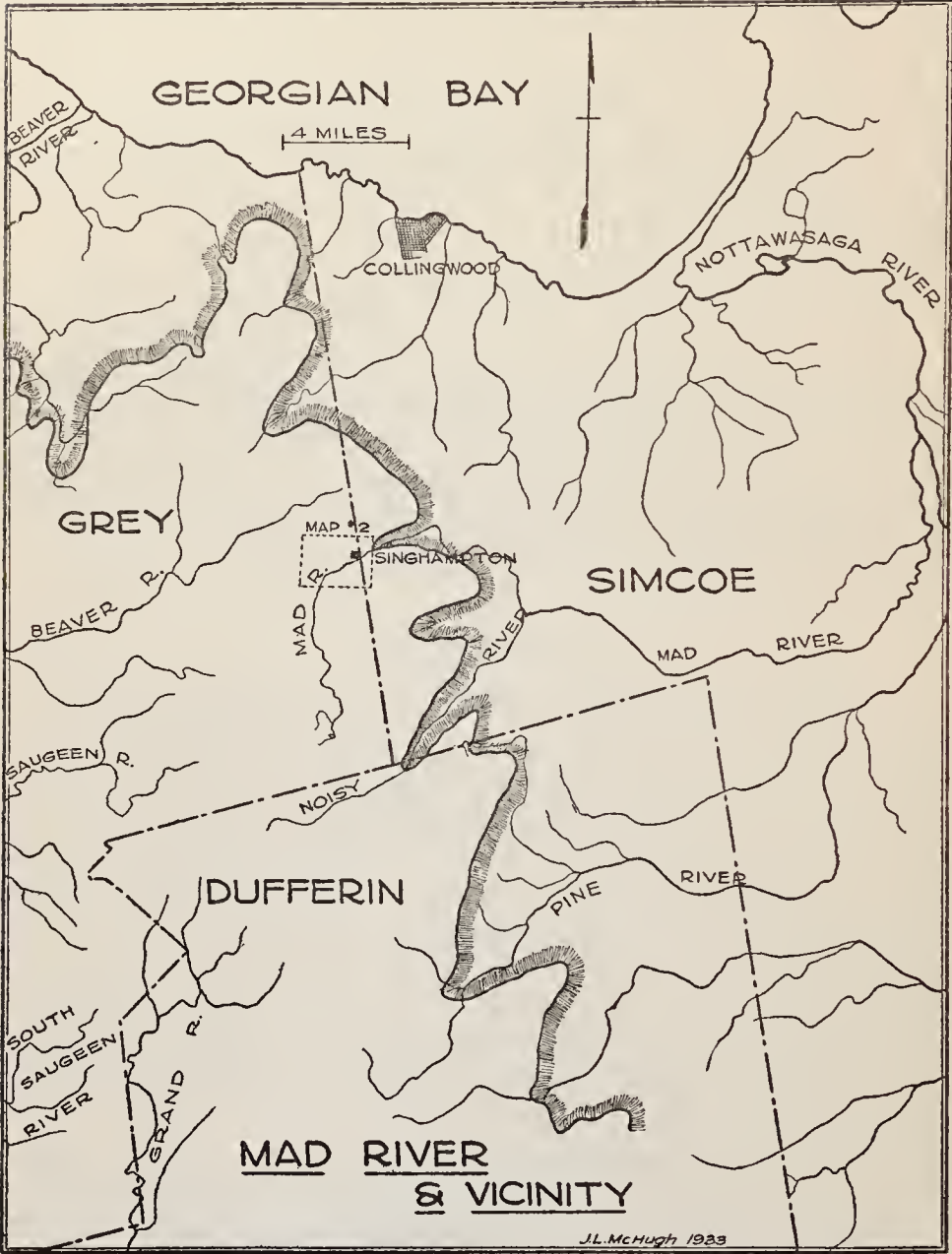


FIGURE 1. Map of Mad river and vicinity

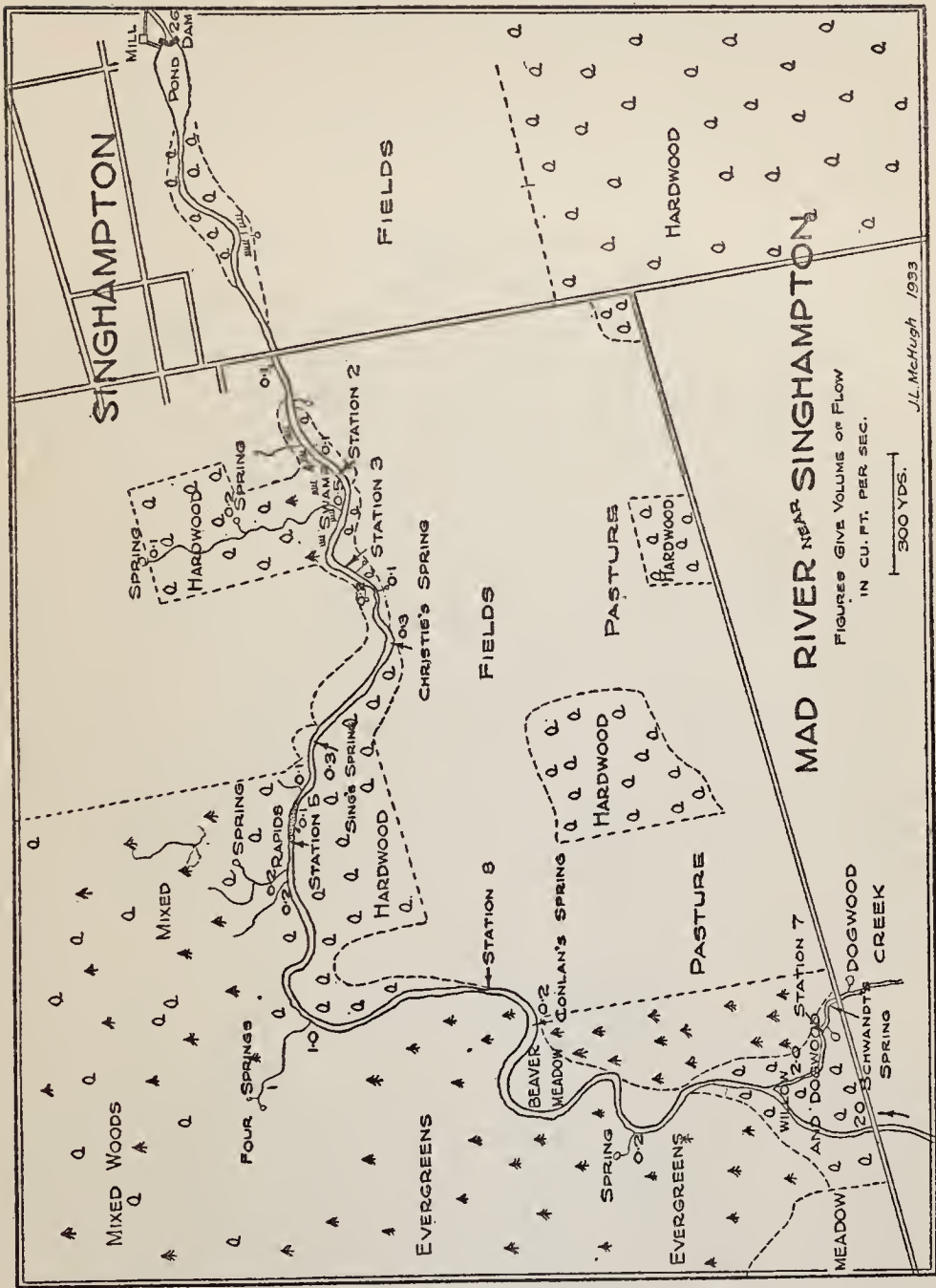


FIGURE 2. Map of Mad river near Singhampton

back. The mill has been in operation for at least 75 years. The extent of the river and of the section studied is illustrated in figures 1 and 2.

Several small tributaries flow into the river along the course of the mile and a half under observation. The largest of these, entering near the upper end, has been called Dogwood creek.

1. Geology

The basic rock of this region is the hard Lockport dolomite, a sediment of Middle Silurian age. It is almost completely covered by glacial drift, consisting of sandy clay, with many large stones, mostly of lime, though a few are of igneous origin, brought from afar during the ice age. The edge of the Niagara Cuesta is close to Singhampton, and over it the river must fall to reach the plain below—a drop of about 600 feet (180 metres). In doing this it has cut a steep narrow valley three miles (5 km.) long, the bottom of which is at one point 300 feet (90 metres) below the level of the table-land immediately above. Along the north side of the glen the uppermost massive layers of dolomite form a perpendicular cliff 50 feet (15 metres) high. In the valley, the river runs swiftly over a stony bottom; this section is distinguished as the “lower Mad river”, and will be discussed below. Above the mill dam, which marks the beginning of the fall, the current is slow; this is the section described here and is referred to simply as “Mad river”.

2. Surrounding Vegetation

Figure 2 shows the distribution of vegetation along the course of the stream. On the north-west a forest extends unbroken for several miles. To the south and east the country is well cleared, and used for pasture and field crops. However, the actual course of the stream is for the most part lined by trees. Near its southern (upper) end is a “beaver meadow”; a swale of *Carex* marking the site of an old beaver pond. The forest consists of the common de-

ciduous hardwoods on most of the high ground, mixed with black ash, white elm, cedar, or even tamarack in moister locations, as at the river's edge. Pine seems to have been rare, even in early days; a few stands of balsam and white spruce occur on sandy knolls.

The Mad river has suffered less from deforestation of its headwaters than have many Ontario streams. Many hundred acres of land just south of the area under study are covered by damp forests of cedar, balsam, spruce, and tamarack; the effect of this large area of bush is to retain the water, lessen the spring floods, and give permanence to the many springs of the region. Certainly, however, enough of the land has been cleared to make the river's volume of flow higher in the spring and lower in the summer than was formerly the case.

3. Climate

Singhampton is situated in the highlands of southwestern Ontario, at an altitude of about 1,500 feet (460 metres). This has a rather important effect on the climate: *Temperature*. Not extreme. The maximum summer temperature in 1930 was 86° F. (30° C.), while the nights were always cool. The earth freezes and is covered with snow some time in December; it does not thaw until the latter part of March. Winter minimum temperatures would probably be -25° to -40° F. (-32° to -40° C.).

Wind. Proximity to lake Huron may account for a very noticeable tendency toward strong steady westerly winds, especially in the winter and early spring.

Rainfall. The average precipitation in the Mad river region is fairly constant throughout the year, at about three inches (7.6 cm.) per month. It is least in August and greatest in December. In every month of 1930, considerably less than the usual amount of moisture fell, culminating in a drought during August and September. Table 5, showing precipitation at Eugenia, a town 13 miles (21 km.) west of

TABLE 5. Precipitation at Eugenia, Ontario, in inches *

	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	De.
Average Rainfall for 15 years	0.4	0.4	1.6	2.0	3.0	3.5	3.3	2.2	2.9	2.9	2.0	1.0
Snowfall	26.7	22.3	10.7	3.6	1.7	...	...	...	0.1	3.6	14.5	24.8
Total**	3.0	2.6	2.7	2.3	3.1	3.5	3.3	2.2	2.9	3.3	3.4	3.5
1930 Rainfall	0.4	0.7	0.3	0.9	2.1	2.7	1.0	0.2	0.6	0.3	0.1	0.2
Snowfall	13.5	12.5	13.5	4.0	...	...	...	...	...	18.0	9.0	12.5
Total**	1.7	1.9	1.6	1.3	2.1	2.7	1.0	0.2	0.6	2.1	1.0	1.4

*These figures are for the years 1916-30.

**Ten inches of snow equals 1 inch of rain.

Singhampton and at nearly the same elevation, has been supplied through the courtesy of Dr. J. Patterson, director of the Canadian Meteorological Service.

4. Physical Features of the River

Contour and bottom. An ideal cross-section of the Mad river in the section under consideration would be as in figure 3. It consists of a central channel (B) and on each side a

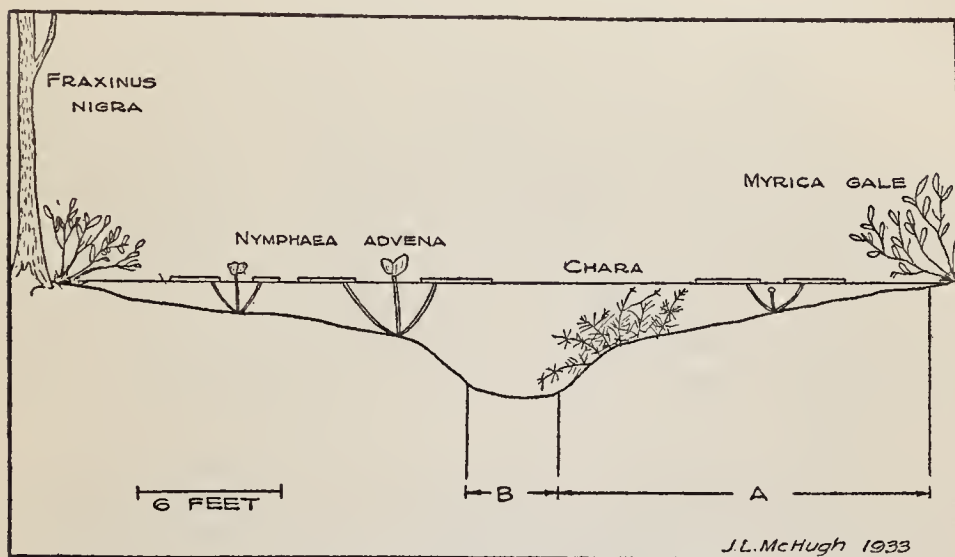


FIGURE 3. Cross-section of Mad river

shallow flat (A). The bottom of region A is of mud, and supports a flora of mud-loving plants. Its depth is 0 to 3.5 feet (1.2 metres). The central region B has an average depth of about four feet, its bottom is of "marl gravel"—small bits of limestone about one cm. in diameter; it may hold a profuse growth of aquatic plants, but is often bare. Logs and sticks are abundant, chiefly in the shallow area, and soon become lime-encrusted.

This typical section is fairly well represented at station 3 or station 8. (The location of the various stations is shown in figure 2.) Variations are of three sorts: first, an increase in the width and depth of the channel, chiefly at bends,

which form pools up to nine feet (2.7 metres) in depth, as at station 2; second, an increase in the extent of the shallow region, best represented by the broad flooded borders of the river near the mill dam; third, a decrease in depth of the channel and absence of mud flats, with which is correlated an increase in current speed and a bottom of larger stones—*i.e.* an approach to the rapid water conditions seen in the lower Mad river. Station 5 is of this type.

Rate and volume of flow. Table 6 shows the determinations made of current speed and volume at station 5. The greatest volume was determined at the time of the spring flood in 1931; in other years the volume of flow has risen far above this figure. On the other hand, the lower figures are probably near the absolute minimum, on account of the extreme dryness of the season. Station 5 represents almost the maximum current speed in this section of the river during the time it was studied. The more typical sections, such as station 3, had speeds somewhat less than this figure, averaging perhaps 0.2 feet (0.06 metre) per second in July and August.

The variations in volume of flow were accompanied by corresponding variations in water-level of about two feet. In addition, the level of the lower part of the stream is controlled by the stop logs of the mill dam. Its influence was felt up-stream past Christie's spring to the first shoal, a distance of five-eighths of a mile (one km.). This section was subject to daily variations in level of about a foot, during the summer, due to the intermittent flow of water through the mill. Hence all levels in this section have been referred to a standard, which is taken as the level on May 20, 1930.

Water supply. Most of the water in this section of the stream comes from the upper reaches, but added to this is the flow of the small spring feeders and of springs in the river bed. Each of these has been marked on figure 2, along with its estimated volume of flow on July 25, 1930. It will be

TABLE 6. Physical and chemical characteristics of the Mad river at stations 3 and 5

		Rate of flow (feet per second)	Volume of flow (cubic feet per second)	Temperature		pH.	Oxygen		
				°C.	°F.		cc/l.	p.p.m.	Per cent. satura- tion
Station 3	May 21, 1930.....	..	..	13.0	55.5	7.8	7.5	10.7	103
	June 9, 1930.....	..	..	14.5	58.	7.8	7.0	10.0	100
	July 4, 1930.....	..	..	17.6	63.5	..	7.5	10.8	114
	July 25, 1930.....	..	..	21.0	70.	..	5.3	7.6	86
	August 16, 1930...	..	..	19.8	67.7	..	7.0	10.0	111
	September 4, 1930.	..	..	14.7	58.5	7.8	5.4	7.7	77
	October 20, 1930..	..	..	4.2	39.5	7.8	8.8	12.5	100
	November 20, 1930	..	..	8.8	48.	..	..	..	..
	January 17, 1931..	..	..	0.8	33.5	7.5	6.9	9.8	71
	March 21, 1931...	..	..	0.4	33.	7.7	8.0	11.4	82
	April 19, 1931.....	..	..	11.3	52.5	7.3	6.3	9.0	87
	May 17, 1930.....	1.3	65	12.0	53.5	7.8	7.0	10.0	94
	June 11, 1930.....	..	..	14.5	58.	..	..	..	..
Station 5	July 22, 1930.....	0.5	25	22.0	71.5	..	..	..	..
	September 3, 1930.	0.3	12	19.2	66.5	8.0	7.0	10.0	110
	October 20, 1930..	0.4	13	2.2	36.	7.7	8.4	12.0	90
	January 18, 1931..	..	..	0.9	33.5	7.6	8.0	11.4	83
	March 21, 1931...	..	8	0.2	32.5	7.7	7.5	10.7	79
	April 20, 1931.....	1.7	250	10.8	51.5	7.4	5.6	8.0	78

seen that of a total flow of 26 cubic feet (0.74 cubic metre) per second at the mill, about 20 cubic feet per second comes from the main stream, and six cubic feet per second from feeders. Springs are numerous throughout the region, but not all are permanent.

II. Physical and Chemical Properties of the Water

1. Temperature

A recording thermometer was mounted at station 2, with its bulb lying in the shade of a small log at a depth of four feet (3.3 metres) on the edge of the channel zone. It was in action almost continuously from June 13 to September 7. Figure 4 is an example of one of the records. From these graphs and the daily record of maximum and minimum air temperature, we may draw the following conclusions:

a. The water reaches its maximum temperature between 4.30 and 6.00 p.m. It averaged 5.30 p.m. for the week ending June 28, and 5.00 p.m. for the first week in September. On cloudy days the maximum is reached one and a half hours earlier than on clear days.

The water drops to its minimum temperature between 7.00 and 9.00 a.m., averaging 7.45 in June and 8.30 in September, on bright days. On dull days the temperature may continue to drop until noon or even until 3.00 p.m.

Although no definite figures are available, it is clear that these maxima and minima lag behind the corresponding air temperatures. In summer the minimum air temperature is reached about 5.30 a.m., and the maximum about 3.30 p.m. Figure 5 illustrates this lag graphically.

b. The factor most influential in warming the water during the day is the direct radiation of the sun, rather than the temperature of the surrounding air. This is illustrated in figure 4; July 26 was the only dull day in the week, the others had a sky nearly free of clouds. Even more striking is figure 6A, in which maximum air and water temperatures

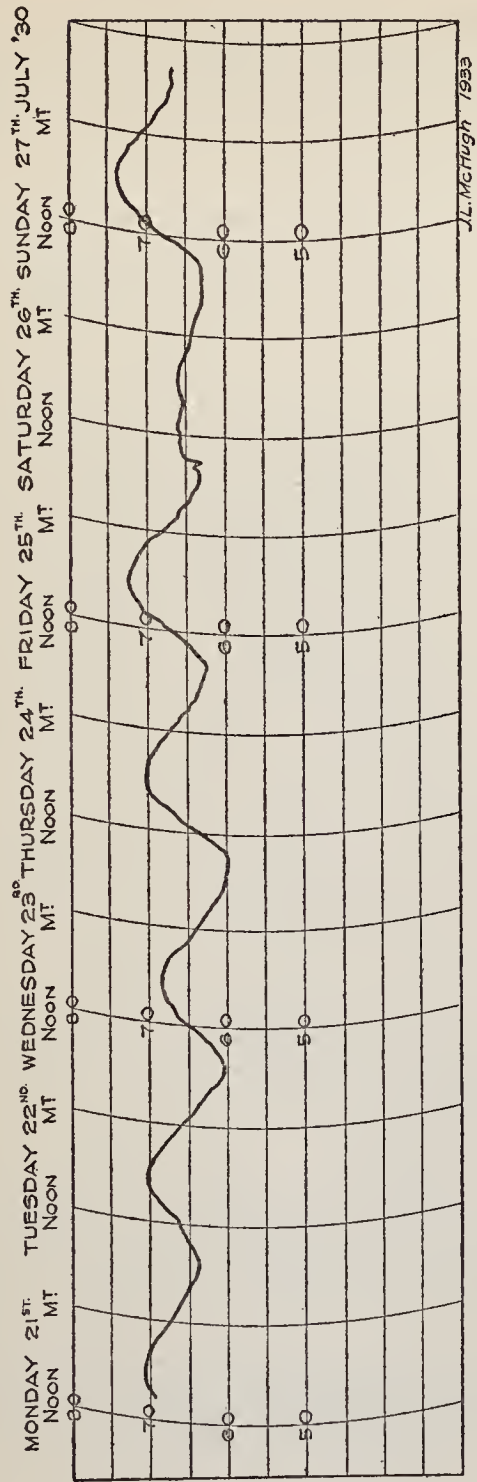


FIGURE 4. Temperature Fahrenheit of Mad river, July 21-28, 1930. Corrected for constant error of thermometer.

are plotted together. On five different occasions the water temperature rose *above* that of the air, in one case as much as 6° F. (3.3° C.) This occurred only on clear days, when the sun's radiation was strong.

The relation between minimum temperature of air and water, shown in figure 6B, is less obvious, but it is probable that air temperature is more active in regulating the lower extreme of water temperature than the higher. The other factor tending to lower the water temperature of the river

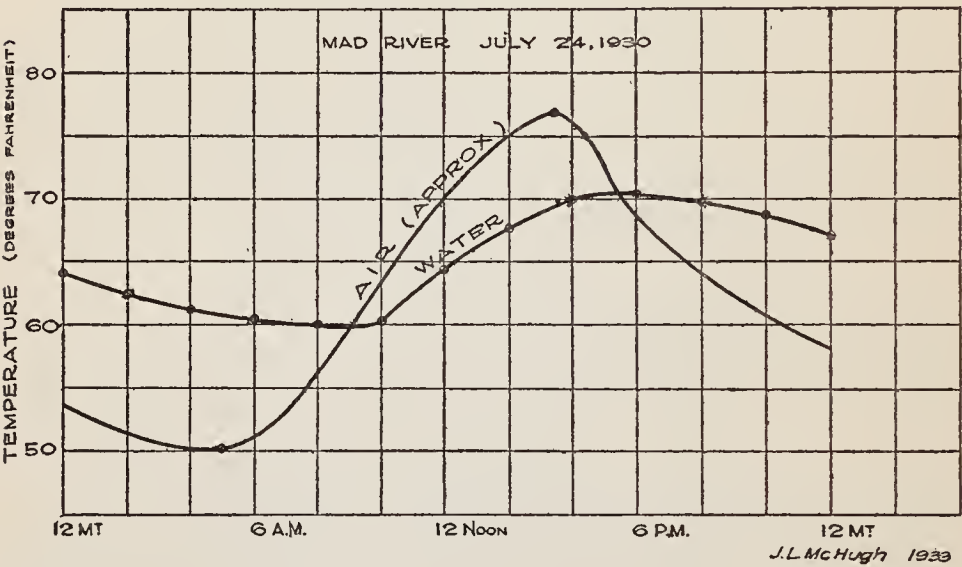


FIGURE 5. Daily fluctuation in temperature of air and water at the Mad river

is, of course, the influx of cold water from springs and creeks. On one occasion this was sufficient to cause a drop below the minimum air temperature.

In winter diurnal variations in temperature are very slight, as shown in figure 7; 33.6° F. (0.9° C.) was the highest temperature recorded, while for most of the day it remained at 32.0° F. (0.0° C.).

c. Seasonal variation in temperature in the section near stations 3 and 5 is shown in table 6. The readings were taken on a bright day, usually at 3.30 p.m.

2. Dissolved Oxygen

The water of a river would tend to be saturated with respect to oxygen at all times, were it not for the following factors:

a. Variation in atmospheric pressure; solubility of oxygen increases with increase in pressure.

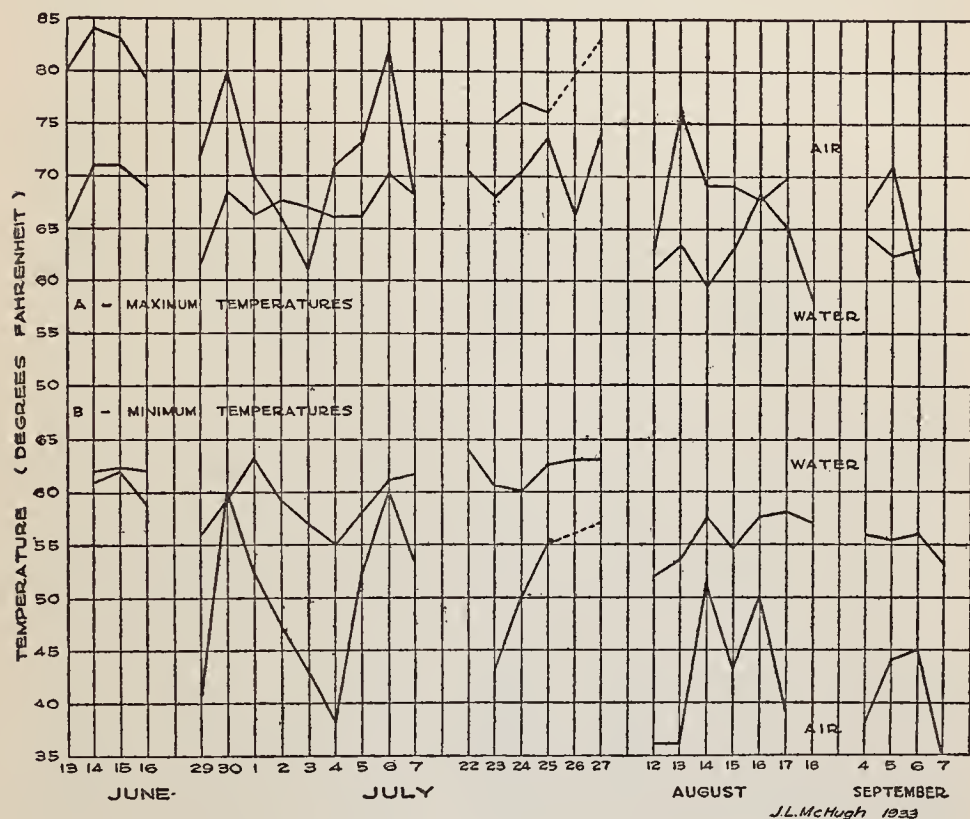


FIGURE 6. Maximum and minimum temperatures of air and water at the Mad river, June-September, 1930

b. Variation in temperature of the water; solubility decreases with increase of temperature.

c. Influx of water of different oxygen content from springs or elsewhere.

d. Photosynthetic activity of green plants, which tends to increase the amount of dissolved oxygen; this occurs only in the presence of the sun's radiation.

e. Respiratory activity of plants and animals of all sorts, which tends to decrease the amount of dissolved oxygen; this continues at all times, but during the day its effect upon the oxygen content of the water may be obscured by the reverse process, plant photosynthesis.

Where water is in contact with the atmosphere, there is

TABLE 7. Diurnal variation in water conditions of the Mad river at station 2

Date	Time	Temperature		pH.	Oxygen		
		°C.	°F.		cc/1	p.p.m.	Per cent. sat.
1930	8.30 a.m.	14.8	58.7	...	4.5	6.4	64
August 16	12.30 p.m.	16.6	61.9	...	5.8	8.3	86
"	5.15 p.m.	19.8	67.7	...	6.4	9.1	101
"	8.40 p.m.	18.9	66.0	...	7.0	10.0	110
"	12.30 a.m.	17.4	63.4	...	6.0	8.6	91
August 17	4.30 a.m.	15.6	60.0	...	4.7	6.7	68
"	7.15 a.m.	15.0	59.0	...	5.0	7.1	72
"							
1931	8.15 a.m.	0.0	32.0	7.7	7.0	10.0	69
March 23	10.15 a.m.	0.2	32.5	7.7	7.5	10.7	73
" 21	12.30 p.m.	0.4	33.0	7.7	...	...	..
" 22	3.40 p.m.	0.4	33.0	7.7	8.0	11.4	78
" 21	5.30 p.m.	0.6	33.0	7.7	8.4	12.0	81
" 22	9.35 p.m.	0.0	32.0	7.7	7.8	11.1	76
" 21	12.15 a.m.	0.0	32.0	7.7	7.3	10.4	71
" 22							
April 19	10.00 a.m.	8.4	47.2	7.3	5.9	8.4	77
"	2.10 p.m.	11.3	52.3	7.3	6.3	9.0	87
"	5.35 p.m.	12.6	54.6	7.4	6.1	8.7	87
"	8.00 p.m.	12.2	54.0	7.4	5.9	8.4	83
"	11.15 p.m.	11.4	52.6	7.4	5.5	7.9	77
"	6.30 a.m.	9.5	49.1	7.2	5.3	7.6	71
April 20	9.15 a.m.	9.8	49.7	7.3	5.5	7.9	74
"	12.20 p.m.	11.5	52.7	7.3	6.0	8.6	84
"							

an exchange of gases, which counteracts the action of these factors and tends toward saturation. In a slow stream like the Mad river, this process is comparatively weak, and consequently the water is often supersaturated with respect to oxygen by day, and unsaturated by night. Below important falls or long rapids, the water of a river is usually saturated with respect to oxygen both day and night. Diurnal

variation of the oxygen content of the water in August and March is shown in table 7 and illustrated in figures 7 and 8.

In summer the time of maximum oxygen content follows that of maximum temperature by about two hours, *i.e.* at 8.00 p.m., while the time of minimum oxygen content occurs about three hours earlier than the minimum temperature, at 5.00 a.m. It is interesting also to note that

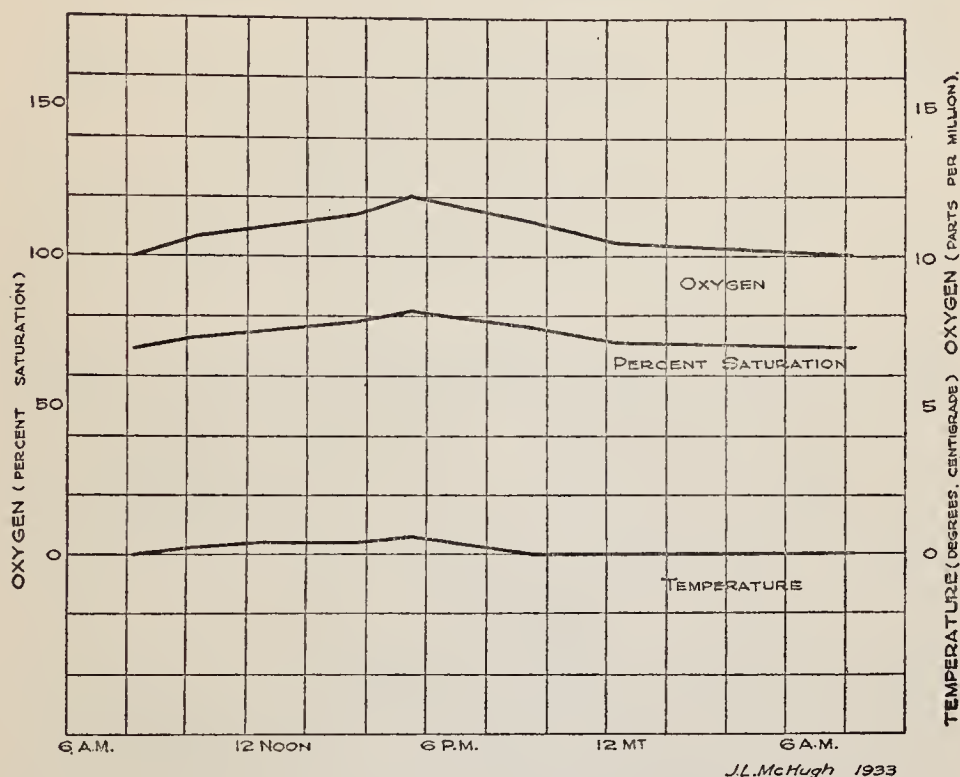


FIGURE 7. Fluctuation in temperature and oxygen content of the Mad river, March 21-23, 1931

from 5.00 p.m. to 10.00 p.m. the water was supersaturated with oxygen, this reaching 110 per cent. about eight o'clock in the evening. Determinations made on other occasions showed even higher supersaturation. In this slow and fairly deep section of the river, the principal agents in aerating the water are green plants. The effect of the sun's radiation on the photosynthetic activity of plants becomes apparent

earlier in the morning and continues later in the evening than its effect on the water temperature.

In winter, the processes of respiration and photosynthesis are retarded by the low temperatures; hence the amount of oxygen dissolved in the water varies much less than in summer, only between 10.0 and 12.0 parts per

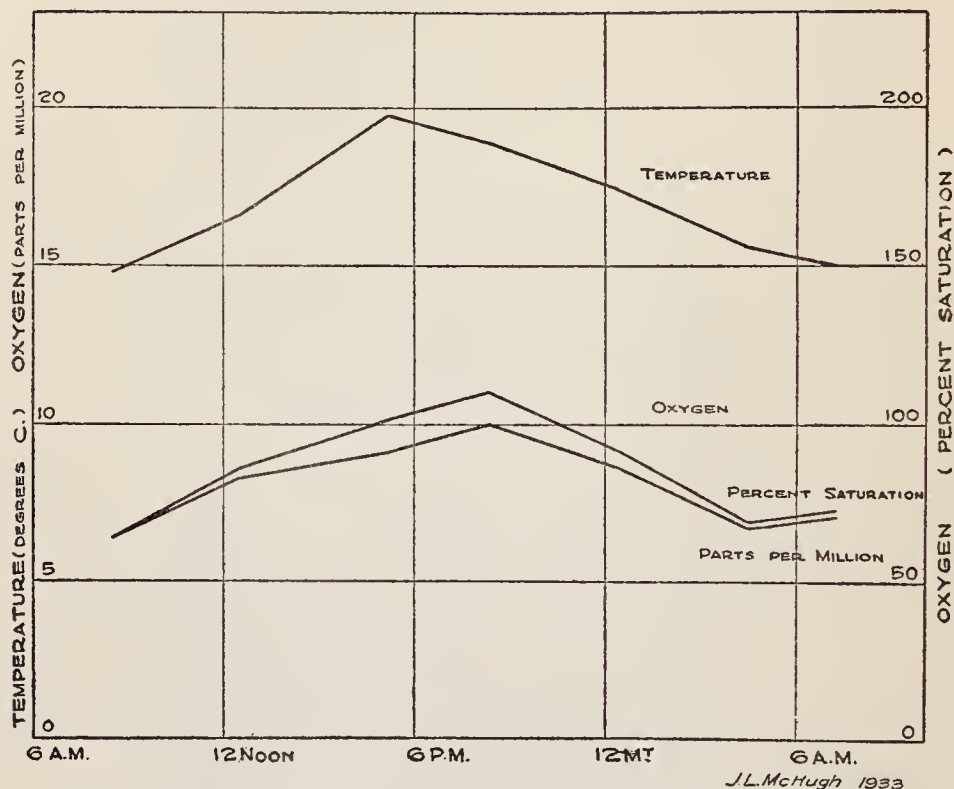


FIGURE 8. Fluctuation in temperature and oxygen content of the Mad river, August 16-17, 1930

million. The peak is reached about 6.00 p.m., and the minimum probably about 7.00 a.m.

The seasonal variation in oxygen content is shown in table 6 and figure 9. Most, but not all, of the readings were taken about 3.00 p.m., and when varying weather conditions are taken into account, it is obvious that these determinations cannot be very exactly representative of the month in which they were taken. Nevertheless, on the basis of these and

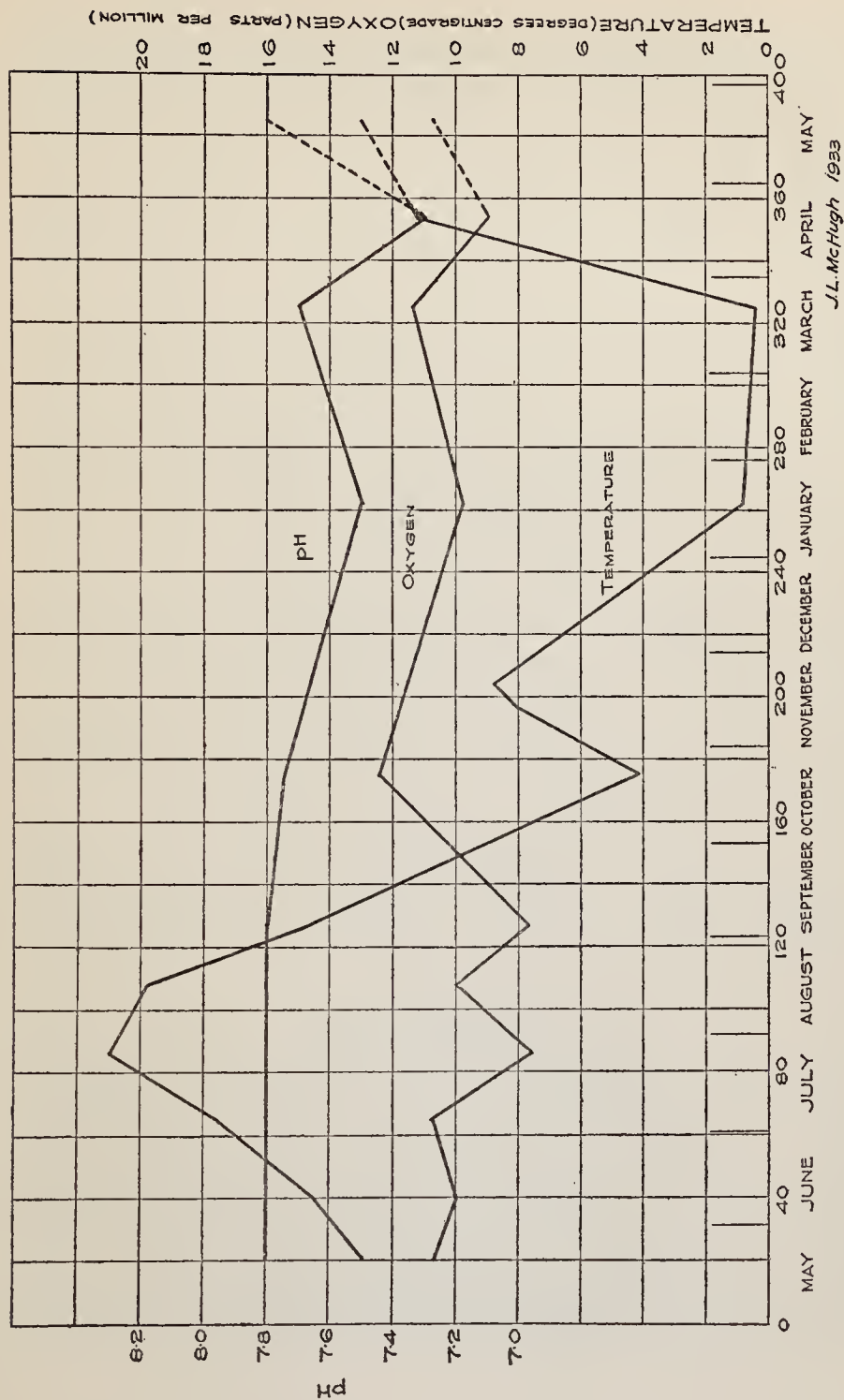


FIGURE 9. Seasonal variation in temperature, pH, and oxygen content of the Mad river, 1930-1931

other observations, the seasonal tendencies might be accounted for as follows: from May to December plant photosynthesis is more than sufficient to saturate the water with oxygen, with the result that the oxygen content is controlled by temperature. Considering the value at 3.30 p.m. on a bright day, it falls from about 11 parts per million in May to 9 parts per million in July, then rises to 13 parts per million when the water has cooled again in October. During winter respiratory processes are retarded only by the lower temperature; photosynthesis, on the other hand, may also be retarded by the shortening of the day and by the weakness of the light which penetrates the thick mantle of snow and ice. Hence the amount of dissolved oxygen will depend more directly on the output of the plants. This is evidenced by the fall of the oxygen with decreasing sunlight between October and January from 12.5 to 9.8; and by its rise again in March to 11.4 parts per million, when the intensity and duration of the solar radiation has increased. During the spring flood, in April, the oxygen drops once more to about 9.0 parts per million, because many of the plants have been swept away from the stream bed and the photosynthetic activity of the remainder is not sufficient to saturate so large a volume of water.

On one point we may be assured: at no time of day or year does the amount fall near the 2.5 parts per million minimum required for the existence of speckled trout (Gutsell, 1929).

3. Carbon Dioxide

The carbon dioxide content of the Mad river (table 8) was quite low throughout the year. On April 19 it was greater in the morning than in the evening. The diurnal changes would probably be the reverse of the changes in oxygen content, *i.e.* an increase in carbon dioxide at night owing to respiration of organisms of every kind, and a decrease by day resulting from the photosynthetic activity of green plants. Carbon dioxide is never present in large

quantities in the stream, because any excess combines with the abundant lime of the stream bed to form a soluble acid carbonate. Conversely, the carbon dioxide content is not reduced to zero by the assimilating plants, because many of them are able to free the carbon dioxide from this combination and use it in their metabolism, depositing the normal carbonate either in their own tissues (*Chara*), or on the surface of their stems and leaves (*Potamogeton*), or on sticks and stones of the river bed (some microscopic algae). In weed-filled ponds, particularly those containing much *Spirogyra*, carbon dioxide is often reduced to zero on bright summer days, and streams flowing from such ponds may be alkaline to phenol phthalein, *i.e.* contain normal carbonates. Such was the case below the mill pond on the Noisy river (table 8).

4. Dissolved Solids

Titration with methyl orange revealed the presence of large quantities of acid carbonate in the Mad river (nearly 200 parts per million expressed as CaCO_3) and a rough test with soap solution showed a high proportion of calcium and magnesium (270 parts per million as CaCO_3). These quantities were reduced to one-half of their normal value during the spring flood (table 8). The limited data available indicate that the withdrawal of carbon dioxide and precipitation of normal calcium carbonate during the course of plant photosynthesis are not sufficient to cause significant diurnal variation in the acid carbonate content of the water of this stream. The low value in spring is, of course, the result of the influx of a large volume of melted snow. It is probable that at this season much of the lime precipitated on the stream bed during summer is redissolved and carried away. The net result over a period of years is, however, a gradual accumulation of carbonate, which forms the "marl-gravel" bottom of the stream. In the Pine river the author has seen stones up to four inches in diameter, formed by the addition of concentric layers of precipitated lime about a small stick or pebble; such stones crumble easily in the hand.

5. Hydrogen-ion Concentration

Greenfield (1920) has shown that the carbon dioxide content, acid carbonate content, and hydrogen-ion concentration of natural waters are connected by the following formula:

$$(H^+) = \frac{4.0 \times CO_2 \times 10^{-7}}{(HCO_3^-)} + 1 \times 10^{-8}$$

where (H^+) is the hydrogen-ion concentration, in grammes per litre, CO_2 is the carbon dioxide content, expressed as parts per million of CO_2 , (HCO_3^-) is the bicarbonate content (or "alkalinity") expressed as parts per million of $CaCO_3$. This relationship he has more conveniently expressed in the form of a nomogram published by Shelford (1925). From these calculations we may deduce that:

(1) the pH of a river will decrease (become more acid) with increase in carbon dioxide content;

(2) the pH of a river will increase (become more alkaline) with increase in bicarbonate content;

(3) if the pH of a river is greater than 8.0 it contains no free carbon dioxide;

(4) if the pH of a river is less than 8.0, it in all probability contains some free carbon dioxide. (Free mineral acids have the same effect, but are not found in unpolluted waters.)

The large proportion of acid carbonate in the Mad river is responsible for the rather low hydrogen-ion concentrations (high pH) recorded throughout the year (tables 6, 7, 8). In summer the pH ranged from 7.8 to (rarely) 8.0, but did not exceed that figure, as it often does in ponds (Ricker, 1932b). The lesser values recorded during winter (7.5 in January and 7.7 in March) are probably the result of an increased carbon dioxide content at this time, which in turn is the result of the decreased photosynthetic activity, as explained above. At the time of the spring flood, the alkalinity of the water is cut in half, and the pH has the correspondingly low value of 7.4.

TABLE 8. Analyses of spring and river waters. Acid carbonate, normal carbonate, and hardness are expressed as parts per million of calcium carbonate (CaCO_3)

Body of water	Date	Time	Temperature		pH.	Oxygen			Acid carbonate (HCO_3)	Normal carbonate (CO_3)	Free carbon dioxide (CO_2) p.p.m.	Hardness Drops p.p.m. of soap sol.
			°C.	°F.		cc/l.	p.p.m.	Per cent. sat.				
Mad river, near source	June 11, 1930	.....	12.0	53.5	7.6	7.8	11.2	105	180	0	2.	12.
Mad river, station 2	June 9, 1930	9.15 a.m.	12.8	55.	7.8	7.4	10.6	101	193	0	3.5	16.
Mad river, station 2	March 23, 1931	8.15 a.m.	0.0	32.	7.7	7.0	10.0	71	187	0	0.7	16.
Mad river, station 2	April 19, 1931	10.00 a.m.	8.5	47.2	7.3	5.9	8.4	77	97	0	2.2	6.
Mad river, station 2	April 19, 1931	8.30 p.m.	12.2	54.0	7.4	5.9	8.4	83	100	0	1.1	6.5
Dogwood creek	April 20, 1931	2.50 p.m.	13.0	55.5	7.3	5.8	8.3	82	120	0	...	7.5
Noisy river	June 11, 1930	.....	16.0	61.	8.0	7.8	11.1	114	178	16	0	14.
B. N. spring	June 13, 1930	.....	6.5	43.5	7.1	2.6	3.7	31	189	0	7.	14.
B. N. spring	March 22, 1931	10.30 a.m.	7.5	45.5	7.1	3.4	4.9	41	187	0	7.	17.
B. N. spring	April 21, 1931	10.45 a.m.	5.8	42.5	7.2	4.7	6.7	59	135	0	4.4	9.

*See p. 46.

Diurnal variations in pH could not be certainly detected during the summer nor in March, owing to the buffer action of the acid carbonate. In April, when the last named was less abundant, the pH rose to 7.4 during the day and fell to 7.2 at night.

It may be noted here that the author has found no very close agreement with Greenfield's formula in the CO_2 , HCO_3 , and pH determinations he has made, owing perhaps to faulty technique in titrating for carbon dioxide. The figures given for carbon dioxide concentration in table 8 should be compared only among themselves.

6. Springs

Springs are somewhat different from the main stream in the physical and chemical properties of their waters. They probably show no significant diurnal variation in these respects. The peculiar characteristics of spring water as compared with the river would seem to be: temperature low and nearly constant at about 6.5°C. , low oxygen content of about four parts per million, low pH—7.1, and a high carbon dioxide content. As the water flows away from the spring, it quickly gains oxygen, and more slowly loses carbon dioxide and rises in temperature. Many springs, however, have an oxygen content much higher than the above, sometimes as much as ten parts per million. Seasonal variation, in the case of B. N. spring (figure 2) was evident chiefly in temperature and carbon dioxide content, as shown in table 8. The temperature was lowest in April at the time of the floods, and the highest recorded was during the winter. No readings were taken at midsummer, however. It would seem that in spring the flood waters enter the spring, lowering its temperature, increasing its oxygen content, and decreasing its carbon dioxide content, alkalinity, and hardness. The effect of this admixture does not last more than a month.

Some animals appear to be susceptible to the peculiarities of spring water. Trout congregate on the three river-bed springs of the Mad river to some extent during summer,

and very noticeably during the spawning season—probably a temperature reaction. *Gammarus* was not found in the Mad river, nor yet in its tributary, Dogwood creek, except in one situation in each stream, where spring water was coming up from below.

III. Aquatic Vegetation

1. Emergent Littoral Plants

In some places, typical woodland or pasture flora extends down to the bank of the river, and gives way at once to the aquatic forms. Usually, however, the shore area is marked by a distinct littoral association of plants, some of which are partly submerged at all seasons, some during high water only. The more important, in order of their occurrence from the land toward the water, are as follows. (The letter following the name of a plant indicates how common was its occurrence: A—abundant, F—frequent, O—occasional, R—rare, in descending order of magnitude.) Mr. R. F. Cain, of the University of Toronto, has assisted in making the determinations.

Cornus stolonifera. A.

Myrica Gale. A, the commonest plant of the shore region. Like the preceding, it forms dense tangles at the water's edge.

Carex spp. F, various species of sedge are abundant in the "beaver meadow" but are found only in scattered patches elsewhere.

Phalaris arundinacea. O, forms clumps of "marsh grass" at intervals along the lower stretches of the stream.

Eleocharis spp. R, found rarely as an outlier of *Phalaris* or *Carex*.

The above plants were submerged only in the spring. Those to follow grew with stems in the water throughout the summer.

Equisetium fluviatile. R, seen commonly near station 8.

Sparganium sp. R, the emergent form of this reed was not common.

Sagittaria latifolia. O.

Radicula nasturtium—*aquaticum*. O, common in some parts of the beaver meadow section. It might equally well be classified with the true aquatic plants.

2. True Aquatic Plants

About nine-tenths of the total bottom area of the stream provided anchorage for various sorts of aquatics. The bare tenth was of three types: (a) parts of the channel marl; (b) muddy borders where the plants were killed by summer fluctuations in water-level; and (c) deeper mud banks whose vegetation had been washed away by the spring floods.

Plants of the mud flats

Nymphaea advena. A, although perhaps strictly speaking an emergent species, this is characteristic of the zone of true aquatics. It was the most abundant plant of the mud flats in the slower parts of the river.

Chara sp. A, grew in all situations up to a depth of five or six feet (two metres): common in all parts of the river. It apparently gives way to the more deeply rooted *Nymphaea*.

Ranunculus circonatus (?). O, the white water-crowfoot resembled *Chara* in habit but was much less common.

There was a reciprocal relation between the distribution of the last two plants, and the muddiness of the bottom. While the plants preferred a soft substratum, their tangled stems were themselves efficient collectors of silt, so that the muddy areas encroached upon the comparatively bare marl.

Plants of the central channel

Hippuris vulgaris. O.

Potamogeton natans. R.
Sparganium sp. F.
Sagittaria sp. O.
Potamogeton amplifolius. F.

These five were characteristic of the marl of the channel. Their roots did not collect mud as did the above forms, so that the water flowed through them comparatively rapidly. The first three were almost confined to the reaches above station 5; the last two were also seen in the slower reaches below. Both the *Sparganium* and the *Sagittaria* were not of the typical upright form, but had linear and flexible leaves which waved in the current. Absence of fruiting bodies made specific determination impossible.

Mosses. Submerged logs were often covered with mosses, especially if they stood out from the bottom.

Algae. No particular study was made of the distribution of algae other than *Chara*. Large filamentous forms occasionally attracted notice on the bottom, and, with diatoms, appear in the food of some fish.

IV. Aquatic Invertebrates

1. List of Species

Oligochaeta

Tubificidae. Occasional.

Lumbriculidae. Rare.

Hirudinea

Helobdella stagnalis (L.). Occasional.

Glossiphonia complanata (L.). Occasional.

Macrobdella decora (Say). Rare.

?*Haemopsis marmoratis* (Say). Occasional.

Haemopsis plumbeus Moore. Frequent.

Crustacea

Cladocera, Copepoda, and Ostracoda occurred in abundance, but were not studied systematically.

Amphipoda

Hyalella knickerbockerii (Bate). Frequent.

Decapoda

Cambarus propinquus Girard. Frequent. The food of five specimens consisted chiefly of fragments of vascular plants with some diatoms and other algae, and one Baetid nymph.

C. bartonii robustus. Rare.

Insecta

Ephemeroptera. Imagos and nymphs were identified by Mr. F. P. Ide of the University of Toronto.

Ephemeridae

Hexagenia viridescens. Occasional.

Ephemera sp. cf. *simulans*. Abundant. The alimentary canals of seven specimens, taken May to November, contained much sand, organic debris, fragments of vascular plants, and a few diatoms and filamentous algae.

Baetidae

Leptophlebia mollis. Occasional.

Leptophlebia debilis. Rare.

Blasturus nebulosus. Abundant.

Ephemerella temporalis. Frequent.

Caenis sp. Frequent.

Baetis pygmaeus. Occasional.

Centroptilum convexum. Rare.

Centroptilum bellum. Rare.

Chloeon sp. Rare.

Heptagenidae

Siphonurus sp. Frequent.

Ecdyurus tripunctata. Frequent.

Ecdyurus canadensis. Occasional.

Ecdyurus sp. (*fusca* group). Rare.

Heptagenia hebe. Rare.

Odonata. Imagos and nymphs were identified by Dr. E. M. Walker of the University of Toronto.

Zygoptera

- Ischnura verticalis* (Say). Rare.
- Enallagma ebrium* (Hagen). Rare.
- Enallagma boreale* (Selys).
- Agrion aequabile* (Say). Occasional.
- Agrion maculatum* Beauvois. Rare.

Anisoptera

- Aeshna umbrosa* Walker. Rare.
- Tetragoneuria spinigera* Say. Rare.
- Somatochlora minor* (Calvert). Rare.

Neuroptera

- Sialis* sp. Frequent.
- Chauliodes* sp. Rare.

Trichoptera. Larvae were identified with the aid of Lloyd (1921), Lestage (1921), and Needham and Needham (1930). Dr. Cornelius Betten of Cornell University has identified the imagos collected.

Hydroptilidae

- Hydroptila* sp. Rare.

Hydropsychidae. Collected rarely in the stony section.

Polycentropidae

Neureclipsis sp. Occasional. The loose nets of this species were commonly seen trailing from logs in a moderate to slow current.

?*Polycentropus* spp. Occasional. Three species of larvae which appear to fall into this genus were found in the stream, on marl or stony bottom.

Plectrocnemia canadensis Bks. Imagos, 12. vi. 30.

Plectrocnemia sp. 8. Imagos, 27. vii. 30. The larvae referred to *Polycentropus* may belong here.

Phylocentropus sp. Frequent. Imagos, *P. placidus* Bks., 8-12. vi. 30.

Lype sp. Imago only, 7. vi. 30.

Sericostomatidae

- Goera* sp. Rare.
- Lepidostoma* sp. Rare.

Helicopsyche borealis Hagen. Frequent. Imagos, 2-7. vii. 30.

Molannidae

Molanna sp. Occasional. Imago, *M. cinerea* Hagen, 17. vi. 30.

Leptoceridae

Leptocerus sp. Imagos only, 12-13. vi. 30.

Oecetis sp. Occasional. Imago, *Oe. incerta*, 8.vii.30. .

Trienodes sp. Occasional. Imagos, 12. vii. 30.

Mystacides sepulchralis Walker. Abundant. Imagos, 8. vii.-14. viii. 30.

Phryganeidae. Larvae of two species were occasional in early spring, and common in trout stomachs. The food of four specimens was chiefly of animal matter: Chironomine larvae and a Hydroptilid caddis larva, with about 15 per cent. vegetable debris.

Imagos, *Ptilostomis* sp., 15. vi. 30; *P. semifasciata*, 12. vi. 30; *Phryganea*? *sayi*♀

Limnephilidae. Many of the larvae taken could not be identified even as far as genus.

Limnephilus indivisus. Imagos, 12-23. vi. 30.

Larvae of this species were abundant in April in temporary pools, and may occur in the river itself.

Limnephilus sp. 34. Imagos, 5. ix. 30. A common cross-stick larva of the river is probably to be referred to this species.

Rheophylax submonilifer. Imago, 8. vii. 30.

Anabolia bimaculata. Imago, 4. viii. 30.

Halesus guttifer. Imagos, 5. ix. 30. Larvae frequent; many specimens have the dorsal spacing hump partially or wholly inverted, in which case they resemble *Stenophylax scabripennis* as described by Lloyd (1921).

Neophylax sp. cf. *autumnus*. Larvae rare.

Heteroptera. Corixidae have been identified by Mr. G. Stuart Walley, of the Entomological Branch, Ottawa.

Corixidae

Palmacorixa nana Walley. Frequent.

Arctocorixa modesta Abb. Occasional.

Arctocorixa vulgaris Hungfd. Occasional.

Belostomidae

Benacus griseus. Rare.

Nepidae

Ranatra americana. Rare.

Nepa apiculata. Rare.

Gerridae

Gerris sp. Occasional.

Diptera. Larvae of Chironomidae were identified by Dr. O. A. Johannsen of Cornell University, imagos of Tabanidae and Empididae by Dr. C. H. Curran, of the American Museum of Natural History.

Tipulidae

Antocha sp. Rare.

Ceratopogonidae

Culicoides sp. Frequent.

Chironomidae

Tanypinae

Pentaneura (*Ablabesmyia*) group *flavifrons*.

Pentaneura (*Ablabesmyia*) group *monilis*.

Procladius group *adumbratus*.

Clinotanypus.

Chironominae

Chironomus subgenus *Cryptochironomus*.

Chironomus subgenus *Microtendipes*.

Chironomus subgenus *Endochironomus*.

Tanytarsus.

Simuliidae

Simulium sp. Occasional.

Tabanidae

Chrysops indus O.S.

Chrysops carbonarius Walker.

Larvae of *Chrysops* were rare.

Empididae

Rhamphomyia irregularis Loew. Imagos were rather common in May, swarming close to the water.

Coleoptera. Imagos of this order were determined by Mr. W. J. Brown, of the Entomological Branch, Ottawa.

Haliplidae

Haliphus immaculicollis Harr. Rare.

Dytiscidae

Hydroporus depressus Fab. Occasional.

Hydroporus solitarius Sharp. Occasional.

Gyrinidae

Gyrinus sp. Rare. Larva taken.

Hydrophilidae. Rare.

Helmidae

Helmis quadrinotatus Say. Occasional.

Chrysomelidae

Donacia proxima Kby. Rare.

Donacia hirticollis Kby. Rare.

Donacia pusilla Say. Rare.

Arachnida

Hydracarina. Water mites were occasionally collected but have received no systematic attention.

Mollusca

Gastropoda. Chief Justice F. R. Latchford, of Toronto, has determined most of the species.

Valvatidae

Valvata tricarinata (Say). Frequent.

Amnicolidae

?*Amnicola limosa* (Say). Rare.

Lymnaeidae

Lymnaea stagnalis L. Rare.

Stagnicola caperata (Say). Rare.

Planorbidae

- Helisoma trivolvis* (Say). Rare.
Gyraulus parvus (Say). Frequent.
Gyraulus deflectus (Say). Rare.

Ancylidae

- Ferissia rivularis* (Say). Rare.
Ferissia parallela (Haldeman). Rare.

Pelycypoda. The Sphaeriidae have been determined by Dr. V. Sterki, of New Philadelphia, Ohio.

- Pisidium compressum* Say. Frequent.
Pisidium variable Prime. Frequent.
Pisidium sargenti Sterki. Occasional.
Pisidium sp. (near *sargenti*). Frequent.
Pisidium sp. Occasional.
Musculium sp. (immature). Rare.
Sphaerium rhomboideum (Say). Frequent.

2. Ecological Distribution of Invertebrates

The distribution of the invertebrates in the above list will be discussed, by a reference to typical habitats. Unless otherwise indicated, records of insects are based on immature stages. The unit of bottom studied was 144 square inches (929 square cm.). As explained above, *abundant* species are represented by 16 or more examples in that area, *frequent* species by 6 to 15 examples, *occasional* species by two to five and *rare* species by only one.

Shore region.

(a) Among the grass along the shore (*Phalaris arundinacea*); depth of water 0 to 4 inches. From June to January this region was dry. One collection: May 20, 1930.

Abundant forms

Arctocorixa adults and nymphs of *Palmacorixa*.

Frequent forms

Ephemerella temporalis, *Siphonurus* sp., *Limnephilid* B.

Occasional forms

Limnephilid C, *Chrysops*, *Culicoides*, *Stagnicola*.

Rare forms

Oligochaeta, *Helobdella stagnalis*, *Hyaella knickerbockerii*, *Halesus guttifer*, *Limnephilid A*, *Pentaneura* (group *flavifrons*), four species of Chironominae, *Haliphus immaculicollis*, *Lymnaea stagnalis* (immature), *Gyraulus deflectus*, *Pisidium*.

(b) Mud bottom, near shore, partly covered by leaves, grass stems, and small sticks; depth 0 to 3 inches. One collection: June 17, 1930.

Occasional forms

Corixidae, *Chrysops*, Chironominae, *Culicoides*, *Pisidium*.

Rare forms

Oligochaeta, *Macrobdella decora*, *Haemopsis plumbeus*, *Helobdella stagnalis*, *Limnephilid E*, *Stagnicola*, *Gyraulus parvus*, *Helmis* sp.

Mud-Nymphaea region. Bottom of mud in which are buried the fleshy stems of *Nymphaea*, the leaves of which appear early in spring, and reach the surface in June. Three series of collections were made in this important section: at depths of one, one and a half, and two feet, referred to the standard May level. By June 25 the water had fallen so that the first of these was at times quite dry, the second, barely under water. These fluctuations caused considerable destruction of life; the following species were noted dead on the bottom, presumably killed by desiccation: *Haemopsis marmoratis*, *Halesus guttifer*, *Lymnaea stagnalis*, *Planorbis trivolvis*.

(a) Depth one foot in May, dry in summer. Collections taken May 20 and June 18.

Abundant forms

Corixidae. Nymphs of *Palmacorixa* were frequent in May; in June the nymphs had disappeared, but adults of *P. nana* were abundant.

Chironomidae. *Procladius* (*adumbratus* group) were occasional in May, and abundant in June, when they were evidently about to pupate. Chironomine D abundant in May.

Sphaeriidae. *Pisidium* was abundant at both times.

Frequent forms

Culicoides. Frequent in May and June.

Clinotanypus A (*pinguis* group). In June some were ready to pupate.

Occasional forms

Hyalella knickerbockerii was occasional in June, absent in May.

Halesus guttifer. Two specimens taken in May.

Arctocorixa sp. Occasional in May.

Tanypine C.

Chironomine N. Occasional in May.

Chironomus (*Endochironomus*) A. Occasional in May.

Chironomine sp.?

Sphaerium rhomboideum.

Rare forms

Oligochaeta, *Ephemera* cf. *simulans*, *Mystacides sepulchralis*, *Phylocentropus* sp., *Sialis* sp., *Clinotanypus* G, other Tanypinae and Chironominae, *Musculium*.

(b) Depth 18 inches in May, fluctuates in summer to a minimum of one inch. Collections taken May 21, June 9, July 4, July 27, August 12, September 4, October 20, January 17.

Abundant forms

Palmacorixa nana. Nymphs frequent in May, adults frequent in June and abundant in early July.

Culicoides. Abundant in May and June, occasional at other times.

Clinotanypus A (*pinguis* group). Abundant in winter, and frequent in May and June.

Chironomine Q. Abundant in winter, not found at other times.

Pisidium. Abundant in May and June, frequent at other times.

Frequent forms

Hyalella knickerbockerii. Frequent in winter and early spring; occasional or rare at other times.

Ephemera cf. *simulans*. Of scattered distribution in the silt beds; abundant in some collections and rare in others.

Phylocentropus sp. Pupae taken up to early June; young larvae first appear late in July, and are occasional to frequent until the following June.

Clinotanypus A (*pinguis* group). Abundant in winter, frequent in May and June.

Clinotanypus H. Frequent to rare from early July to October.

Procladius B (*adumbratus* group). Mostly occasional or rare, but abundant in early July.

Chironomus (*Microtendipes*) I. Abundant in winter, not found again.

Chironomine Q. Abundant in winter, not found again.

Occasional forms

Tubificidae. Usually occur.

. *Haemopis plumbeus*. Occasional or rare throughout the year.

Sialis sp. Usually rare, but small larvae were abundant early in September.

Blasturus nebulosus. Frequent in winter, absent at other times.

Arctocorixa modesta. September and October.

Tanyptine C. Absent from late July to September, occasional at other times.

Chironomus (*Endochironomus*) A. Occasional in May and June.

Chironomus (*Cryptochironomus*) B. Occasional from May to early July.

Chironominae. Several small species found occasionally or rarely in some of the collections.

Rare forms

Lumbriculidae, *Glossiphonia complanata*, *Dina parva?*, *Hexagenia viridescens*, *Baetis pygmaeus*, *Mystacides sepulchralis*, *Halesus guttifer*, *Limnephilid* B, *Phryganea* sp., *Pentaneura* E (group *flavifrons*), *Clinotanypus* G, other Tanypinae, *Helmis quadrinotatus*, *Hydroporus solitarius*, *Hydroporus depressus*, *Sphaerium rhomboideum*.

(c) Depth 24 inches in May, minimum summer level six inches. Collections made on May 20, June 14, July 5, July 27, August 13, September 4, October 20, January 17.

Abundant forms

Phylocentropus sp. Frequent to abundant, except during emergence in June and early July.

Arctocorixa modesta. Abundant in late summer and fall.

Procladius B (*adumbratus* group). Occasional in spring, abundant in summer and fall.

Frequent forms

Hyalella knickerbockerii. Frequent in summer and fall, occasional in winter and spring.

Culicoides. Frequent or occasional, except in June.

Clinotanypus A (group *pinguis*). Frequent in May and June.

Clinotanypus H. Frequent during July and August.

Tanypine C. Frequent from September to spring.

Chironominae. Several small species frequent in certain dredgings.

Pisidium. Occasional in spring, frequent from summer to winter.

Occasional forms

Haemopis plumbeus. Occasional or rare.

Hexagenia viridescens. Of scattered distribution in this area.

Ephemera cf. *simulans*. Commoner than the last, but equally irregular in appearance.

Sialis sp. Usually occasional in occurrence, frequent in winter.

Arctocorixa sp. This spring form was occasional in June.

Palmocorixa nana. Occasional in June.

Sphaerium rhomboideum. Frequent to absent.

Musculium sp. Occasional or absent.

Rare forms

Tubificidae, *Glossiphonia complanata*, *Cambarus propinquus*, *Caenis* sp., *Ephemerella temporalis*, *Agrion aequabile*, *Halesus guttifer*, *Limnephilid* C, *Limnephilid* D, *Phryganeid* A, *Chironomus* (*Microtendipes*) I, *Chironomus* (*Cryptochironomus*) B, *Chironomus* (*Endochironomus*) A, *Chrysops* sp., *Helmis* sp., *Valvata tricarinata*, *Helisoma trivolvis* (young), *Ferissia parallela*.

Summary of the mud-Nymphaea section. This region is characterized chiefly by the abundance of Chironomoidea: Chironominae in shallower water and Tanypinae in deeper water, with Culicoides throughout. Corixidae are common at moderate depths, with three different species reaching peaks of abundance about June 1, July 1, and September 15 respectively. The abundant caddis is *Phylocentropus*, which builds its branching mud tubes in the deeper water. Among mayflies, *Hexagenia viridescens* and *Ephemera* cf. *simulans* form scattered colonies; *Blasturus nebulosus* is frequent in winter. *Hyaella knickerbockerii* is a frequent species occurring in fairly constant numbers. Clams were common, *Sphaerium rhomboideum* in deep water, and several species of *Pisidium* in shallow water, though the latter may migrate outward during the summer drought. The large *Helisoma trivolvis* and *Lymnaea stagnalis* were often observed upon the stems and leaves of *Nymphaea*, but only rarely appear in the samples. *Haemopsis plumbeus* and *Sialis* sp. were of occasional occurrence throughout.

In addition to the above typical forms, stragglers from the shore region, from the deeper waters, or from the weed

beds, appear in the collections. In the first class are included the large caddis larvae such as *Halesus guttifer*, Limnephilids C and D, *Phryganea* A, and also *Glossiphonia complanata*, *Ephemerella temporalis*, *Chrysops* sp., etc. Weed-bed forms include *Valvata tricarinata*, *Gyraulus parvus*, *Ferissia parallela*, *Baetis pygmaeus*, *Helmis* sp., *Hydroporus* spp., and others, while *Mystacides sepulchralis* and *Caenis* sp. are more at home in the marl gravel of the deeper water.

Muddy weed-bed region. The two aquatic plants most efficient in trapping silt among the stems and roots are *Chara* and *Ranunculus*. Of these *Chara* was much the commoner. It grew at depths from six feet up to water so shallow that its stems were killed from exposure to air during summer. The most extensive beds were at a depth of one and a half to three feet in May.

(a) *Chara beds.* Collections were made at station 2 on May 21, June 9, July 4, July 25, August 12, September 4, October 20, and January 17, and one on July 3 at station 8. The location was near mid-stream, at a depth of 6 to 24 inches, or 14 to 32 inches referred to the May standard.

Abundant forms

Culicoides. Abundant from May to early July, occasional at other times.

Chironomine D. This small member of the Chironominae was abundant from May to early July but absent thereafter.

Pisidium. Abundant up to September, but rare in fall and winter.

Frequent forms

Tubificidae. Frequent from May to July, rare later.

Haemopsis plumbeus. Frequent or occasional throughout.

Hyaella knickerbockerii. Frequent or occasional, except in late summer.

Cambarus propinquus. Not only were small individuals common, but even large specimens were surprisingly frequent in some collections.

Blasturus nebulosus. Frequent in winter only, absent at other times.

Clinotanypus A (*pinguis* group). Found in spring only.

Tanypine H. Frequent from late July to January.

Procladius B (*adumbratus* group). Frequent to rare; commoner from July to January.

Occasional forms

Lumbriculidae.

Phylocentropus sp. Occasional except in early summer.

Trienodes sp. Larvae frequent on July 4, one pupa taken July 25.

Arctocorixa sp.

Tanypine C. Occasional in winter, spring, and early summer.

Chironomine G. Frequent in winter.

Helmis quadrinotatus. Larvae occasional; adults taken in early June.

Hydroporus solitarius. Adults taken in August and October; larvae of *Hydroporus* were occasional in late July and August.

Sphaerium rhomboideum. Occasional in most collections.

Gyraulus parvus. In three collections.

Rare forms

Glossiphonia complanata, *Haemopsis marmoratis*, *Hexagenia viridescens*, *Ephemera* cf. *simulans*, *Siphonurus* sp., *Baetis pygmaeus*, *Centroptilium convexum*, *Somatochlora minor*, *Oectis* sp., *Halesus guttifer*, *Lepidostoma* sp., *Palmacorixa nana*, *Pentaneura* K (*flavifrons* group), *Pentaneura* I (*monilis* group), *Procladius* G, several small Chironominae not included above, *Chironomus* (*Cryptochironomus*) B, *Chironomus* (*Microtendipes*) G, *Chironomus* (*Microtendipes*) I, *Hydroporus depressus*, *Musculium* sp., *Valvata tricarinata*, *Amnicola limnosa*?

(b) *Ranunculus beds*. Only two collections made: on June 18 near station 2, depth 12 inches, current speed about 0.5 feet per second; and on July 3 at station 8, depth about eight inches, and current speed about 1.5 feet per second.

Abundant forms

- Arctocorixa* sp. June only.
- Pisidium* spp. Abundant in both situations.
- Valvata tricarinata*. June only.

Frequent forms

- Tubificidae. July only.
- Glossiphonia complanata*. July only.
- Helobdella stagnalis*. July only.
- Hyalella knickerbockerii*. July only.
- Limnephilid B. June only.
- Chironomine M. Both collections.
- Helmis quadrinotatus*. Adults and larvae frequent in July.
- Donacia* sp. Two larvae and three pupae on July 3.
- Adults of *D. hirticollis* were common on July 25.
- Gyraulus parvus*. Frequent in both situations.

Occasional forms

- Cambarus propinquus*. Both situations.
- Baetinae. Specimens lost.
- Halesus guttifer*. Prepupae and pupae in July.
- Triaenodes* sp. Larvae and pupae in July.
- Oecetis* sp. Pupae in July.
- Pentaneura* K (*flavifrons* group). July only.
- Chironomus* (*Cryptochironomus*) B.
- Chironomus* (*Endochironomus*) H.

Rare forms

- Lumbriculidae, Limnephilid C, Limnephilid D,
- Culicoides* sp., *Clinotanytus* A (*pinguis* group),
- Tanypine C, two small Chironominae, *Tanytarsus* sp., *Hydroporus depressus*, *Sphaerium rhomboideum*.

Summary of muddy weed beds. The fauna of these weed beds may be divided into two parts: (1) those animals

living on or among the stems and leaves of the plants, and (2) those living on or in the mud below. In the first class may be included *Triaenodes* sp., *Helmis quadrinotatus*, *Arctocorixa* sp., Chironomine D., Chironomine M, *Hydroporus* spp., *Valvata tricarinata*, and *Gyraulus parvus*. Those frequenting the mud include the Oligochaetes and leeches, *Hyaella*, *Cambarus propinquus*, *Blasturus nebulosus*, *Phyllocentropus* sp., various *Limnephilids*, *Culicoides*, *Procladius* B (*adumbratus* group) and other Tanypines, the large Chironomines, and the Sphaeriidae.

The striking feature of the association is the large number of crayfish present; among these plants they find shelter denied to them elsewhere in the stream. Next in bulk come the leeches, chiefly *Haemopsis plumbeus*, which are likewise of common occurrence. The burrowing mayflies are almost entirely absent; they seem to avoid loose silt. Among caddis, the interesting *Triaenodes* seems peculiar to this habitat; *Oecetis* and certain *Limnephilids* also occur. Midges are chiefly represented by the abundant *Culicoides*, a frequent Tanypine (*Procladius*), and a small Chironomine which probably lives on the surface of the weeds; other forms are commoner on the surrounding bare mud. The diving beetles *Hydroporus solitarius* and *H. depressus*, while abundant nowhere in the stream, were commonest in this association; *Helmis quadrinotatus* was occasional. Sphaeriidae, especially *Pisidium*, were present in good numbers.

The above remarks apply chiefly to *Chara*. The principal differences noted in the *Ranunculus* were a much greater abundance of *Arctocorixa* sp. among the stems, the presence of larvae and pupae of *Donacia* sp., and the larger numbers of leaf-living gastropods *Valvata tricarinata* and *Gyraulus parvus*.

Bare marl region. Typically the channel of the river had a bottom of bare marl-gravel, with a few small lime-encrusted sticks. In places it was grown up with ribbon-leaved plants such as *Sparganium* (see below). Two series were collected in this area, at standard depths of four and seven

feet respectively. Only the series from the lesser depth has been examined in detail, but the other appears to be essentially the same.

Shallow series: collections were made on May 21, June 9, July 4, July 26, August 12, September 4, October 20, and January 17.

Abundant forms

Ephemera cf. *simulans*. Extraordinarily abundant in spring and early summer; as many as 250 have been taken per square foot. From September to June both generations occur.

Frequent forms

Caenis sp. Commonest in September.

Mystacides sepulchralis. Larvae September to July, emerging throughout the summer.

Helicopsyche sp. May to September.

Pentaneura E (*flavifrons* group). October to June.

Chironomus (*Microtendipes*) G. January to May.

Occasional forms

Hyalella knickerbockerii. Frequent to absent.

Sialis sp.

Molanna sp. Of regular occurrence throughout the year.

Oecetis sp. Larvae in May, pupae in June.

Chironomus (*Microtendipes*) I. Frequent in October.

Chironomine Q. January only.

Small Chironominae.

Rare forms

Tubificidae, *Haemopsis plumbeus*, *Hexagenia viridescens*, *Ecdyonurus tripunctata*, *Agrion aequabile*, *Polycentropus* B, *Halesus guttifer*, *Arctocorixa* sp., *Procladius* B (*adumbratus* group), *Pentaneura* I (*monilis* group), *Tanypine* C, *Chironomus* (*Endochironomus*) A, *Chironomus* (*Endochironomus*) H, *Helmis quadrinotatus*, *Pisidium* sp., *Sphaerium rhomboideum*, *Gyraulus parvus*.

Summary of bare marl region. The outstanding feature of this habitat is the relatively enormous number of nymphs of *Ephemera*, which constitute over 95 per cent. of its fauna by bulk. *Caenis* was the only other common mayfly. The characteristic caddis larvae bore cases made of sand grains, *Molanna*, *Helicopsyche*, and *Oecetis*; the beautiful *Mystacides sepulchralis* used small bits of wood; *Polycentropus* had no portable case. The Chironomoids were poor in species and in individuals. *Pentaneura* E (group *flavifrons*) and *Chironomus* (*Microtendipes*) G were characteristic, but not abundant; the latter used stones for its case also. A fair number of stragglers from other habitats completed the fauna.

Marl weed beds. The plants of the marly bottom were usually long and slender, and did not collect mud among their stems. The most typical were aquatic forms of *Sparganium* and *Sagittaria*, and *Potamogeton amplifolius*. Unfortunately little collecting was done in this area.

(a) *Sparganium*. A single collection on July 3 at station 8 revealed the presence of the common marl organisms, including abundant *Ephemera* nymphs, and a caddis not found at the lower station; *Goera* sp. *Valvata tricarinata* and *Perlinella*? were probably from the leaves of the plant.

(b) *Potamogeton amplifolius*. Collections from among the leaves and stems on September 4 revealed occasional nymphs of *Agrion aequabile*.

Summary of weed beds. Observations upon the "weeds" of the Mad river show that submerged aquatic plants may affect stream life directly in four ways:

1. They harbour a few animals which cling closely to their leaves or stems, and feed there, e.g. small gastropods, *Helmis* and probably certain Chironomines.

2. They harbour some animals which merely rest among the foliage, e.g. *Triaenodes*, *Arctocorixa* sp., *Cambarus propinquus*.

3. They provide more sheltered situations for some animals of the surrounding mud bottom, and hence increaes

their abundance, *e.g.* *Haemopsis plumbeus*, *Blasturus nebulosus*, *Procladius* B (*adumbratus* group), *Pisidium*, *etc.*

4. Because of accumulation of loose silt or in some other way, they provide a less favourable habitat for others of the same fauna, which accordingly are rare or absent, *e.g.* *Ephemera*, most Tanypinae, and Chironominae, *Phylo-centropus*.

In the case of *Sparganium*, *Sagittaria*, *Hippuris*, and *Potamogeton natans*, the first two effects were the only ones observed; in the case of *Chara* and *Ranunculus* the last two were also apparent.

In addition, certain facts of distribution are not explained by any of the four influences listed above, *e.g.* Corixidae are rarely found in *Chara*, but do not object to *Ranunculus*.

3. Seasonal Variation in Invertebrate Life

From this point of view, bottom organisms may be divided into (1) those which for a considerable part of the year are not in the water, and (2) those which are present in fairly constant numbers throughout the year. This is *almost* equivalent to dividing them into (1) insects, and (2) other organisms.

The second group is less numerous and less important. Oligochaeta, Hirudinea, Crustacea, Corixidae, Dytiscidae, Sphaeriidae, and Gastropoda are the principal representatives. Of these the Corixidae, although almost confined to the water, are not uniformly common throughout the year, but one species follows another in a series of waves. Of the remainder, only two species, *Cambarus propinquus* and *Haemopsis plumbeus*, are common in the food of the speckled trout.

The occurrence of most insects in the stream is interrupted by the fact that they live their adult lives out of water. From the time they emerge until their eggs have hatched and the nymphs grown to macroscopic size, they are not available to the larger fish of the stream. In the

case of Ephemerine mayflies greater continuity of distribution is ensured by the fact that two years must elapse before maturity is reached, and hence there is always at least one generation in the water.

Most of the mayflies and midges, the Phryganeids and many smaller caddis flies, emerge during May and June, and are hence absent from the stream in July. The large Limnephilid caddis emerge in the fall, but spend most of the summer in the dormant prepupal and pupal stages, so that they too are not easily found after July 1. Even the Corixids are relatively uncommon by the middle of that month. Midsummer—July and August—is the time when the insect life of the stream is at its lowest ebb, the only common forms being *Ephemera*, *Caenis*, and a few Chironomids.

Many species of invertebrates are regularly eaten by fish, as is evident from tables 9 to 15. Insects are most readily taken, by trout at least, during the actual act of emergence: in the case of midges the pupal state, in the case of mayflies either late nymphal or sub-imaginal. Caddis flies, however, are usually eaten as larvae. Other vertebrates also help to reduce the numbers of the invertebrates, *e.g.* mergansers and other ducks, bitterns, sandpipers, kingfishers, flycatchers, swallows, bats, *etc.*

4. Summary of Invertebrate Life

Insecta are the most important of the larger invertebrates in the Mad river, but Oligochaeta, Hirudinea, Crustacea, Hydrachnida, Pelycypoda, and Gastropoda also occur. The orders of insects represented are Ephemeroptera (three families), Odonata (four families), Neuroptera (two families), Trichoptera (eight families), Heteroptera (four families), Diptera (five families), and Coleoptera (six families). Of these, Ephemeroptera, Trichoptera, and Diptera are outstanding in number of species and individuals.

The three principal types of *faunal associations* in the Mad river are (1) the shore fauna, (2) the mud-flat fauna, and (3) the marl-gravel fauna, each of which is again divisible

into a bare bottom and a weed-bed association. The shore fauna is characterized by the large Baetid mayflies *Siphonurus* and *Ephemerella temporalis*, and large caddis of the families Limnephilidae and Phryganeidae. Typical members of the *mud-flat fauna* are the mayfly *Blasturus*, the caddis *Phylocentropus*, Sphaeriidae, and particularly larvae of Chironomidae. The marl gravel has as an outstanding inhabitant the burrowing mayfly *Ephemera*, and in lesser numbers the caddis *Molanna* and *Mystacides sepulchralis*.

The total quantity of invertebrate life is not constant the year round. In spring the shore area supports the greatest total weight of organisms, the marl is next, while the mud flats are least productive. In summer the marl is richest, then the mud flats, while the shore is dry and barren. The average dry weight of bottom fauna is comparable to that of small shallow *Chara* ponds and lakes, and greatly in excess of that found in larger lakes.

Seasonal variation in invertebrate life is chiefly the result of the emergence from the water of most insects during their adult life. A majority of the species transform in May and June, so that the invertebrate fauna of the stream is at its lowest ebb during summer and early fall.

An important biological factor, affecting the numbers of aquatic invertebrates, is their destruction by fish and other vertebrates. In the case of insects, this may occur at any stage in their life history, but many species are particularly susceptible during the time of transformation, in the pupal or subimaginal state.

5. Fish other than Trout

The nomenclature and systematic arrangement is that of Jordan's *Manual of the Vertebrates*, 13th edition. Examples of every species have been identified by Professor J. R. Dymond of the University of Toronto. Lengths are in inches measured to the fork of the caudal fin; 1 inch = 2.54 cm.

- 1. *Chrosomus erythrogaster* Rafinesque. Several specimens were taken in the stream two miles above the section considered here, and they may occur farther down.
- 2. *Margariscus margarita nachtriebi* (U. Cox). The only specimen, taken July 25, was 2.75 inches long.
- 3. *Semotilus atromaculatus* (Mitchill). Occasionally taken on a hook, and schools of young about one inch long were seen in stony sections. It is said to have been much commoner about 20 years ago.

Spawning of the creek chub takes place early in June; on June 9, 1930, two ripe males and a female extruding eggs were taken.

The food of five specimens 0.88 to 1.38 inches long taken August 14, 1930, was as follows:

	Per cent. by volume
Larvae of Polycentropidae.....	40
Other? caddis larvae and pupae.....	13
Larvae of Chironomidae.....	20
Adult terrestrial fly.....	7
Gastropod.....	20

The result of the examination of the stomachs of six specimens 3.5 to 7.5 inches long taken May 17 to June 9, 1930, is as follows:

	Per cent. by volume
Diatoms, fragments of vascular plants and bottom ooze.....	52
Heptagenid nymphs.....	5
Unidentified insect.....	5
Gastropod (<i>Lymnaea stagnalis</i>).....	38

The young chub were not found where small trout or most other small fish occur, hence they do not come directly into competition with other stream fish. For the larger specimens, six stomachs are not sufficient for a generalization, but the principal items listed are not found in trout stomachs. The absence of crayfish is surprising. In any case, the scarcity of the species makes it an unimportant factor in the life of the stream as enemy, competitor, or food of the trout.

- 4. *Rhinichthys atronasus* (Mitchill). Occasional or perhaps frequent in the beaver-meadow section, not seen below. The examples collected ranged from 1.5

to 2.75 inches in length. Stomachs of nine specimens taken July 12, 1928, and one taken July 25, 1930, contained the following:

	Per cent. by volume
Nymphs of <i>Ephemera</i>	16
Nymphs of Baetidae.....	20
Larvae of Chironominae.....	50
Pupae of Chironominae.....	3
Terrestrial insects.....	11

This is very similar to the food of sculpins taken at the same time.

TABLE 9. Stomach contents of *Eucalia inconstans*

	7 specimens 0.19-0.63 inches July 21, 1930	11 specimens 1.00-2.06 inches June 17- September 4, 1930
Entomostraca		
<i>Cyclops</i>	11	7
<i>Chydorus</i>	—	7
<i>Bosmina</i>	11	1
<i>Pleuroxus</i>	—	4
<i>Ostracoda</i>	36	18
<i>Hyalella knickerbockerii</i>	—	8
Insecta		
Nymphs of Baetidae.....	—	5
Nymphs of Corixidae.....	—	11
Larvae of Tanypinae.....	—	2
Larvae of Chironominae.....	28	11
Pupae of Chironomidae.....	14	4
Larvae of Tipulidae?.....	—	15
Adult terrestrial fly.....	—	3
<i>Gyraulus parvus</i>	—	4

5. *Eucalia inconstans* (Kirtland). Frequent in the lower section, below station 5. Specimens of the stickleback were most easily obtained in late summer and fall. It was often seen lurking in the shelter of logs, lily pads, *Potamogeton*, or *Chara*. Several individuals appear in the stomachs of the speckled trout.

The food of specimens collected June 17 to September 4, 1930, is presented in table 9.

From a consideration of these percentages, it is evident that the food of the stickleback consists chiefly of Entomostraca and aquatic insects, in approximately equal quantities.

TABLE 10. Stomach contents of sculpins (*Cottus bairdii*) in the Mad river
A. 21 sculpins less than two inches long

	10 specimens 0.50-1.00 inches July 4- October 20, 1931	11 specimens 1.06-2.00 inches June 14- September 4, 1931
Oligochaeta.....	3	—
<i>Cyclops</i>	2	1
<i>Chydorus</i>	3	—
<i>Pleuroxus</i>	1	+
Ostracoda.....	1	6
Nymphs of Heptagenidae.....	—	24
Nymphs of Baetidae.....	20	32
Larvae of <i>Culicoides</i>	—	5
Larvae of Tanypinae.....	14	24
Larvae of Chironominae.....	56	6
Nymphs of Corixidae.....	—	2

B. 35 sculpins 2.05-3.7 inches long, taken May 3-September 4, 1930

	Per cent. by volume
Lumbriculidae?.....	9
Copepoda and Ostracoda.....	+
<i>Hyalella knickerbockerii</i>	1
<i>Cambarus</i> sp.....	5
Nymphs of Perlidae.....	2
Nymphs of <i>Ephemera</i> cf. <i>simulans</i>	42
Nymphs of Heptagenidae.....	8
Nymphs of Baetidae.....	14
Larvae of caddis flies.....	8
Corixidae.....	+
Chironomidae.....	5
<i>Gyrinus</i> larvae.....	1
Vegetable matter.....	1
Stones and sand.....	3

6. *Cottus bairdii* Girard. Abundant everywhere in the stream. During the day sculpins are often seen resting on the bottom among sticks or stones, or are to be found hidden in the *Chara* and other weeds. At night they are probably more active, since a few

were caught in a minnow trap at that time. In winter they frequent the same parts of the stream as during the warm weather. There is no evidence that they congregate on the spawning beds of the trout in the fall to eat their eggs; no sculpins were seen near any of the springs where trout were spawning.

The sculpins' spawning time appears to be about the middle of May. On May 3 and 10 females were taken with eggs nearly ripe; by June 14 specimens were spent. On May 30 eyed eggs and small fish were found in two trout stomachs. On July 3, the young of the year, averaging 0.6 inches in length, were to be found abundantly on bare mud bottom at depths of two to ten inches.

Stomachs for analysis were obtained not only from specimens captured by seine, dip net, *etc.*, but also from specimens which speckled trout had eaten. Table 10 gives the results of these analyses.

It is evident that the young sculpins do not depend to any extent on Entomostracan food, but rather favour Chironomid larvae, among which Chironominae predominate. Small Baetid nymphs, mostly weed-clinging species, are found in even the smallest specimens. Sculpins one to two inches long take fewer Chironomids, which are chiefly of the Tanyptinae and have increased their consumption of mayflies, taking Heptagenidae as well as Baetidae. After reaching two inches in length they begin to eat the burrowing nymphs of *Ephemera* in considerable numbers, so that they form over 40 per cent. of the bulk of their food. Other mayflies make up 22 per cent., Chironomids are reduced to five per cent., and crayfish, stonefly nymphs, caddis larvae, *etc.*, make up the total.

It is noteworthy that sculpins are entirely bottom feeders; no terrestrial insects were found in the stomachs, and with the exception of a very few Chironomid pupae, the aquatics were all in the active

feeding state. Even during the great emergence of *Ephemera* in June, no nymphs about to transform were found in the stomachs. Its fondness for the immature nymphs, and its great abundance, suggest that the sculpin is the principal cause of the rapid reduction in the numbers of that species throughout the summer.

6. The Speckled Trout—*Salvelinus Fontinalis*

The Mad river has been considered a good trout stream from the time of the earliest settlements. Fishing was at first unrestricted; parties came from towns many miles distant to catch spawning trout in the fall and salt them for winter use. Nothing is known to the author of the history of fishing in the stream; whether or not there has been over-fishing in the past, as is suggested above, or fluctuations in numbers of the trout owing to other causes. At present fishing is closed to the public on all parts of the stream included in this survey, and fishing rights are leased either to clubs by the year, or to individuals by the day. It is difficult, therefore, to arrive at an estimate of the number of trout captured in a year, but in the mile and a half under consideration it probably lies between one and two thousand. At least 80 per cent. of these are taken between May 1 and June 15. The average length of the trout caught and kept is about nine inches, the minimum size limit is seven inches. The open season lasted from May 1 to September 15 in 1930.

The stomachs of 265 trout from the Mad river have been examined in order to find their food supply at all times of the year and at all ages. The results are presented in tables 11 to 15. The total volume of food in a stomach was measured by displacement of alcohol in a graduate, or very small amounts were estimated. The volume of each item was then calculated from its estimated percentage of the total bulk. Final averages were obtained by adding together the volumes of each item, and calculating its percentage of the total volume of stomach contents.

All of the trout in these tables were taken from the Mad river itself, not from tributaries. Fingerlings were all obtained in the beaver meadow section (see figure 2), the remainder farther down stream, from station 5 to the mill dam. For the food of fingerlings taken in Dogwood creek see table 4.

Three important causes of variation in the kind and amount of food taken by a trout throughout its life are its increase in size, migration to a different habitat, and the change of the seasons.

Changes with increase in size. The smallest trout examined were taken on May 22, or about three months after they had hatched (table 11). They were lying in shallow water, close to shore, and from this location were able to take a number of small flies and Hymenoptera which fell on the surface of the water, as well as the hopping Podurids which made their home there. More than half of their food, however, was truly aquatic, consisting chiefly of midge larvae, with a Psychodid pupa and many small *Canthocamptus*.

In July, at an age of five months, the trout had increased to almost twice their length in May, and consumed on an average over six times as much food. They were no longer interested in Entomostraca, but their (percentage) consumption of Chironomidae was about the same. Since the fingerlings at this time usually stayed in the middle of the stream, among the weeds, their consumption of terrestrial insects was not as great as before; Cercopidae were the principal victims. These gaps were filled by the larger stream insects—mayflies, stoneflies, and caddis flies; *Ephemera* and *Baetis* were the important genera. Even fish were already represented.

The next size group adequately represented was taken in the lower part of the river in late July and early August. The average length of the individuals in this group was 4.9 inches and they were a year and six months old. Table 12 compares their food with that of fish of larger size. The noticeable changes are a decrease in the amount of the smaller

insect foods with increasing size, and an increase in the larger foods—fish and crayfish. A comparison of the stomach contents of trout of various sizes at other seasons enlarges these observations, so that we may conclude:

TABLE 11. Food of fingerling trout in the Mad river

	May 22 1930	July 8-25 1930	September 6 1930
Number of specimens examined.....	5	11	2
Average length in inches.....	1.04	1.96	2.25
Variation in length.....	0.91-1.25	1.63-2.31	—
Average volume of contents in cubic mm.....	4.5	28.	5.
Average number of Nematoda.....	0	4	9
Vegetable matter.....	—	2	—
Entomostraca: <i>Canthocamptus</i>	9	—	—
<i>Hyalella knickerbockerii</i>	—	5	—
Araneida (spiders).....	—	1	—
Aquatic insects			
Collembola: Poduridae.....	18	—	—
Nymphs of Ephemeroptera:			
<i>Ephemera</i>	—	13	—
Baetidae.....	—	12	90
Nymphs of Plecoptera.....	—	1	—
Larvae of Trichoptera.....	—	3	—
Pupa of Psychodidae.....	9	—	—
Larvae and pupae of			
Chironominae.....	31	37	10
Larvae of Tanypinae and			
<i>Culicoides</i>	4	2	—
Terrestrial insects			
Homoptera.....	—	12	—
Diptera.....	20	2	—
Coleoptera.....	—	2	—
Hymenoptera.....	9	1	—
Unidentified.....	—	5	—
Fish.....	—	4	—
Total surface food.....	47	18	—
Total submersed food.....	53	82	100

(a) Stream insects, principally immature mayflies and caddis flies, bulk large in the stomach contents of smaller trout, constituting about 40 per cent. of the food of those near the legal limit of size (seven inches). In large trout, they average not more than 15 per cent. of the food at most

times of the year. Moreover, the large trout take proportionately more of the larger insects (*Ephemera* nymphs and Phryganeid larvae) than of the smaller. It is also interesting to note that the cases of caddis larvae are most frequently found in the larger specimens; small trout are

TABLE 12. Stomach contents of trout of varying size, July 28-August 14, 1930

Number of specimens examined.....	14	16	5	6
Average length in inches.....	4.9	7.0	8.4	11.3
Variation in length.....	4.2-5.4	6.2-7.8	8.0-9.0	10.0-13.2
Average volume of contents in cubic mm.	120	220	270	1050
Average number of Nematoda.....	6	12	9	106
Seeds of <i>Nymphaea</i>	8	48	16	30
Other vegetable matter.....	+	1	—	—
Pelcypoda: <i>Sphaerium</i>	—	3	—	—
Crustacea: <i>Cambarus</i>	—	6	19	50
Hydrachnida.....	2	—	—	—
Aquatic Insects.....				
Ephemerida: <i>Ephemera</i>	32	8	3	+
Others*.....	1	+	—	—
Trichoptera: Limnephilidae.....	5	2	—	—
Others**.....	3	+	3	—
Larval cases.....	2	2	6	—
Heteroptera: Corixidae.....	21	1	+	+
Gerridae.....	2	—	—	—
Diptera: Chironomidae.....	3	—	—	+
Coleoptera.....	2	1	—	1
Terrestrial Lepidoptera.....	2	—	—	—
Terrestrial Coleoptera.....	—	+	—	—
Fish: <i>Cottus</i>	—	3	35	—
Unidentified.....	8	16	—	6
Trash.....	9	6	17	13
Total surface food.....	2	2	—	—
Total bottom food.....	98	98	100	100

*Includes nymphs of Baetidae.

**Includes larvae of *Molanna*, *Polycentropus* and *Mystacides*, and unidentified pupae.

more dexterous in extracting the "worm" from its hiding place.

(b) Crayfish are rarely found in trout less than six inches long, become important (20 per cent.) in the six to eight inch group, reach a maximum in the eight to ten inch group (35 per cent.), and decline somewhat in larger fish (25 per cent.).

TABLE 13. Stomach contents of trout six to eight inches long

	May 16 to May 24	May 30 to June 1	June 6 to June 14	June 28 to June 30	July 23 to Aug. 14	Sept. 5	Nov. 18
Number of specimens examined.....	36	10	24	10	16	11	7
Average length in inches.....	7.1	7.4	7.2	7.6	7.0	6.7	7.1
Variation in length.....	5.9-7.9	7-7.8	6-7.8	5.1-8.5	6.2-7.8	5-8.2	5.6-7.8
Average volume of contents in cubic mm.....	940	1650	1850	390	220	120	565
Average number of Nematoda.....	13	14	93	67	12	8	19
Seeds of Nymphaea.....	—	—	—	—	48	—	1
Other vegetable matter.....	1	+	+	+	1	—	—
Hirudinea.....	8	14	2	—	—	—	—
Pelecypoda: <i>Sphaerium</i>	—	—	—	—	3	—	—
Gastropoda.....	2	1	+	—	—	—	—
Crustacea: <i>Cambarus</i>	23	29	7	15	6	—	2
<i>Hyalella</i>	+	—	—	—	—	—	—
Arachnida.....	+	—	—	—	—	—	—
Aquatic Insects.....	11	5	74	9	8	60	—
Ephemera: <i>Ephemera</i>	+	7	1	—	—	—	—
<i>Blasturus</i>	+	+	—	—	—	—	—
<i>Siphonurus</i>	5	3	2	11	+	1	—
Others*.....	—	+	—	—	—	—	—
Odonata: Coenagrionidae.....	—	5	1	—	—	—	—
Aeshnidae.....	+	—	—	—	—	—	—
Plecoptera.....	+	—	—	—	—	—	—
Neuroptera: <i>Stalis</i> and <i>Chauliodes</i>	+	—	—	—	—	—	—
Trichoptera: Phryganeidae.....	21	+	+	4	—	3	6
Limnephilidae.....	3	6	1	10	2	—	—
Others**.....	+	2	1	4	+	10	1
Larval cases.....	9	3	+	2	2	5	1
Heteroptera: Corixidae.....	+	2	+	10	1	2	1
Gerridae.....	+	1	—	—	—	—	—
Diptera: Simuliidae.....	1	—	+	—	—	—	—

TABLE 13.—Continued

	May 16 to May 24	May 30 to June 1	June 6 to June 14	June 28 to June 30	July 23 to Aug. 14	Sept 5	Nov. 18
Chironomidae.....	3	+	+	+	—	1	+
Empididae.....	+	+	+	—	—	—	—
Coleoptera.....	—	—	1	—	1	—	4
Terrestrial Lepidoptera.....	—	—	—	—	—	—	—
Terrestrial Diptera.....	—	—	—	—	—	8	—
Terrestrial Coleoptera.....	+	1	+	—	+	—	7
Terrestrial Hymenoptera.....	+	1	+	—	—	—	+
Fish: <i>Cottus</i>	8	17	6	7	3	—	—
<i>Eucalia</i>	—	—	—	17	—	—	—
Unidentified.....	4	3	3	3	16	—	—
Eggs of <i>Salvelinus</i>	—	—	—	—	—	—	75
Trash.....	1	1	1	7	6	11	1
Total surface food.....	2	11	70	12	2	8	7
Total bottom food.....	98	89	30	88	98	92	93

*Includes nymphs of *Hexagenia viridescens*, *Ecdyurus tripunctata*, *Caenis* and other Baetidae, sub-imagos and imagos of *E. tripunctata*, and others.

**Includes larvae of *Molanna*, *Mystacides*, *Helicopsyche*, *Polycentropus*, Hydropsychidae; imagos of *Mystacides*, pupae of Hydroptilidae, and other unidentified pupae and imagos.

TABLE 14. Stomach contents of trout eight to ten inches long

	May 17 to May 24	May 30 to June 1	June 6 to June 14	July 28 to August 4	Oct. 23	Nov. 18
Number of specimens examined	28	12	6	5	3	6
Average length in inches	8.6	8.9	8.8	8.4	8.7	8.7
Variation in length	8.0-9.9	8-10	8.0-9.8	8-9	7.5-9.8	8-10
Average volume of contents in cubic mm.	1800	3630	2480	1370	680	167
Average number of Nematoda	15	16	178	46	28	28
Seeds of <i>Nymphaea</i>	—	—	—	16	—	—
Other vegetable matter	+ +	+ +	1	—	3	5
Hirudinea	+ +	—	—	—	—	—
Pelecypoda: <i>Sphaerium</i>	5	69	13	19	37	4
Crustacea: <i>Cambarus</i>	+ +	+ +	—	—	—	+ +
<i>Hyalella</i>	+ +	+ +	—	—	—	—
Arachnida	—	—	—	—	—	—
Aquatic Insects	8	4	76	3	13	—
Ephemera: <i>Ephemera</i>	1	1	+ +	—	—	—
<i>Blasturus</i>	16	5	+ +	—	—	—
<i>Stiphodon</i>	1	+ +	+ +	—	—	—
Others*	7	+ +	+ +	—	13	—
Trichoptera: Phryganeidae	3	2	—	—	6	—
Limnephilidae	1	1	+ +	3	+ +	—
Others**	7	1	+ +	6	—	—
Larval cases	+ +	1	+ +	+ +	—	—
Heteroptera: Corixidae	+ +	1	+ +	—	3	2
Gerridae	+ +	+ +	—	—	—	—
Diptera: Simuliidae	+ +	—	+ +	—	—	—
Chironomidae	+ +	—	+ +	—	—	—
Coleoptera: Dytiscidae	—	—	—	—	1	—
Terrestrial Diptera	—	+ +	—	—	—	—
Terrestrial Coleoptera	+ +	+ +	—	—	—	9
Terrestrial Hymenoptera	+ +	—	—	—	—	—

TABLE 14.—Continued

	May 17 to May 24	May 30 to June 1	June 6 to June 14	July 28 to August 4	Oct. 23	Nov. 18
Fish: <i>Cottus</i>	43	5	10	35	19	10
Unidentified.....	+	2	—	—	—	—
Eggs of fish: <i>Cottus</i>	—	6	—	—	—	—
<i>Salvelinus</i>	—	—	—	—	—	68
Trash.....	4	2	—	17	7	5
Total surface food.....	2	3	76	0	9	7
Total bottom food.....	98	97	24	100	91	93

*Includes nymphs of *Hexagenia viridescens*, *Ecdyurus tripunctata*, unidentified Heptagenids and Baetids, and a few sub-imagos and imagos.
**Includes larvae of *Molanna*, *Mystacides*, *Oecetis*, *Helicopsyche*, Philopotomidae, Polycentropidae, pupae of Hydropsychidae, and other pupae and imagos.

TABLE 15. Stomach contents of trout ten to fourteen inches long

	May 2 to May 11	May 17 to May 24	June 8 to June 14	July 28 to August 14
Number of specimens examined.....	13	13	4	6
Average length in inches.....	11.0	11.6	11.4	11.3
Variation in length.....	10-13	10-14	10.5-12.8	10-13.2
Average volume of contents in cubic mm.....	4070	1580	16500	1050
Average number of Nematoda.....	14	16	121	106
Seeds of <i>Nymphaea</i>	—	—	—	30
Other vegetable matter.....	+	+	+	—
Hirudinea.....	+	+	—	—
Gastropoda: <i>Gyraulus</i>	+	—	—	—
Crustacea: <i>Cambarus</i>	10	26	—	50
<i>Hyalella</i>	—	+	—	—
Aquatic Insects.....	1	4	99	+
Ephemeroidea: <i>Ephemera</i>	—	1	+	—
<i>Ecdyurus</i> and <i>Blasturus</i>	—	+	+	—
Odonata: Agrionidae.....	—	—	—	—
Coenagrionidae.....	—	+	—	—
Neuroptera: <i>Sialis</i>	3	8	—	—
Trichoptera: Phryganeidae.....	1	+	+	—
Limnephilidae.....	4	4	+	—
Others*.....	—	12	+	—
Larval cases.....	+	+	+	—
Heteroptera: Corixidae.....	+	1	—	+
Diptera: Chironomidae.....	+	—	—	+
Coleoptera: Dytiscidae.....	—	—	—	+
Terrestrial Diptera.....	+	—	—	+
Fish: <i>Colinus</i>	73	30	—	6
Unidentified.....	6	7	—	13
Trash.....	—	2	+	—
Total surface food.....	+	1	100	—
Total bottom food.....	100	99	+	100

*Includes larvae of Hydroptilidae, *Helicopsyche*, *Molanna*, and *Mystacides*. One stomach contained 20 specimens of the last.

(c) Fish are not to be entirely disregarded as a food supply for even the smallest trout. With increasing size, the proportion of fish taken increases; at seven inches it is 15 per cent., at nine inches 30 per cent., and at 12 inches it is not far from 50 per cent.

One important exception to the above statements must be noted. For about ten days early in June trout of all sizes from six inches up feed principally on the emerging nymphs and sub-imagos of *Ephemera*. They made up about 99 per cent. of the total food of the four large specimens, and about 75 per cent. of that of the smaller groups.

Seasonal changes. Tables 13 to 15 are arranged so that the variation in food from month to month may be easily noted. The figures shown must not be taken entirely at their face value. The occurrence of a single large sculpin or crayfish has a great effect upon the percentage recorded, especially where only a few specimens have been averaged. Hence, due consideration must be given to the number of stomachs from which each figure has been calculated.

The total quantity of food taken varies in a similar manner in all of the size groups. Starting at a fairly high figure in mid-May, it reaches a maximum at the time of the great rise of *Ephemera* early in June, drops rapidly immediately thereafter, then falls off more slowly throughout the summer and early autumn to a minimum just before the breeding season. The larger the trout is, the more marked are these fluctuations; on an average, the stomach contents in early June are about ten times as bulky as in early autumn. The increase in volume seen in the six to eight inch class at spawning time is because of the consumption of eggs by the males.

Our only clue to the amount of food taken during winter is given by six specimens averaging six inches in length, taken on January 7, 1931, in a large spring off Dogwood creek. Their stomachs averaged only 70 cubic mm. of food each, consisting of the following:

	Per cent. by volume
Needles of Conifers.....	2
Mollusca: <i>Physa</i>	7
Crustacea: <i>Gammarus</i>	14
Hydrachnida.....	+
Ephemera.....	+
Trichoptera: Phryganeidae.....	15
Limnephilidae.....	24
Heteroptera: Corixidae.....	10
Diptera: Chironomidae.....	22
Coleoptera: Dytiscidae.....	5

Discussion. We have already divided the invertebrate fauna of the river into forms of constant and forms of intermittent occurrence. This distinction may also be detected by an examination of their distribution in the trout stomachs throughout the season. The more important forms may be discussed from this point of view:

Leeches. Exceptional; although present in the stream all year, they were found in the stomachs only in spring.

Cambarus propinquus. Common in the stream and in the stomachs throughout the year.

Ephemera cf. *simulans*. Found throughout the year; excessively abundant at time of emergence.

Siphonurus. Very abundant in a few stomachs near time of emergence.

Phryganeidae. Larvae common in May, and the young appear again in August. In the interval occasional pupae and imagos are taken.

Limnephilidae. Larvae not uncommon in May and June; imagos appear in late June and in October.

Corixidae. Most important in the fall and winter, when a large species is dominant.

Chironomidae. Most commonly taken as pupae in May.

Many of the invertebrates which were found to be frequent or abundant in the stream occur only rarely in the trout stomachs. These are usually forms which burrow deep in the mud, or lie concealed among the weeds, e.g. *Sphaerium*, *Pisidium*, *Haemopsis*, *Ephemerella temporalis*.

Others are protected by their large size and unwieldy exoskeletons, e.g. *Helisoma trivolvis*, *Lymnaea stagnalis*, and the largest crayfish. Still others are concealed for the most of their lives, but become available to the fish at the time of their emergence, e.g. *Siphonurus*, Chironomidae (though many larvae of the latter are eaten by very small trout). *Blasturus* rivals *Ephemera* in abundance in the stream, but early in the spring the nymphs migrate shoreward and transform in the flood pools and shallow borders. Hence they escape the attention of the trout during the period covered by our food study, the only individuals commonly found in the stomachs being female imagos which have returned to the water to lay their eggs. Finally, there are a few forms which are common in the stream and equally so in the stomachs: *Ephemera*, Phryganeid and some Limnephilid caddis flies, Corixidae.

Vegetable materials are found in trout stomachs from a variety of habitats, but not usually in large quantities. The seeds of *Nymphaea*, taken by the Mad river trout at midsummer, are a rather unusual item.

7. Vertebrates other than Fish

Amphibia. *Rana clamitans* Latreille, the green frog, was common among the lily pads along the lower section of the river. Year-old tadpoles were often seen along the mud banks in water up to two feet deep. The stomach of one contained chiefly mineral matter (mud), with a slight admixture of diatoms, filamentous algae, fragments of higher plants, and organic debris. One or two of the records of "unidentified fish" in the stomach contents of trout may be referable to this animal.

Other Amphibia known to frequent borders of the river during their spawning season are: *Bufo americanus* Halbrook, *Hyla versicolor* LeConte, *Rana pipiens* Schreber.

Reptilia. No reptiles were observed in or near the river. The absence of turtles is noteworthy.

Aves. Many species of birds are directly or indirectly connected with the life of the river. Only those more obviously related to the stream life can be discussed.

Lophodytes cucullatus (L.). A hooded merganser was seen several times on the river during the fall. An immature specimen, collected on November 20 by Mr. Arthur Neff, contained the following food organisms:

	Per cent.
Filamentous algae.....	1
Three crayfish— <i>Cambarus propinquus</i>	99
One Corixid.....	+

Anas rubripes Brewster. A flock of a dozen black ducks came down to the river at times during late summer and autumn, and were observed to be feeding over the mud bottom. Sphaeriidae suggest themselves as probable components of their food. A flock of domestic ducks was also observed to frequent the lower part of the river.

Botaurus lentiginosus (Montagu). American bittern. At least one pair nests each year in a swale along the bank of the river. They were observed feeding in shallow water.

Actitis macularia (L.). Spotted sandpipers. Frequented the stream all summer.

Tringa solitaria Wilson. Solitary sandpiper. Rare.

Oxyechus vociferus (L.). Killdeer plover. Occasional.

Streptoceryle alcyon (L.). Kingbird.

Sayornis phoebe (Latham). Phoebe.

Quiscalus quiscula aeneus Ridgway. Bronzed grackle.

Petrochelidon albifrons (Rafinesque). Eaves swallow. A small colony nested within 100 yards of the river.

Hirundo rustica erythrogastris Boddaert. Barn swallow.

Seiurus noveboracensis (Gmelin). Water thrushes. Frequented the shores, under overhanging shrubbery.

Turdus migratorius L. Robin.

Flycatchers and swallows are drawn into stream ecology, as destroyers of aquatic insects in their winged state. No data are at hand as to the extent of their depredations.

Phoebes have been observed to catch and eat imagos of *Perla* and *Chauliodes*, and a sub-imago *Hexagenia viridescens*. Doubtless many other birds destroy mayflies and caddis flies when they are resting on leaves or bark.

The bittern, sandpipers, and, to a lesser extent, the plover, regularly feed by the river's brim, and their food was doubtless chiefly immature aquatic insects. During exceptionally low water, when many *Chara* beds were laid

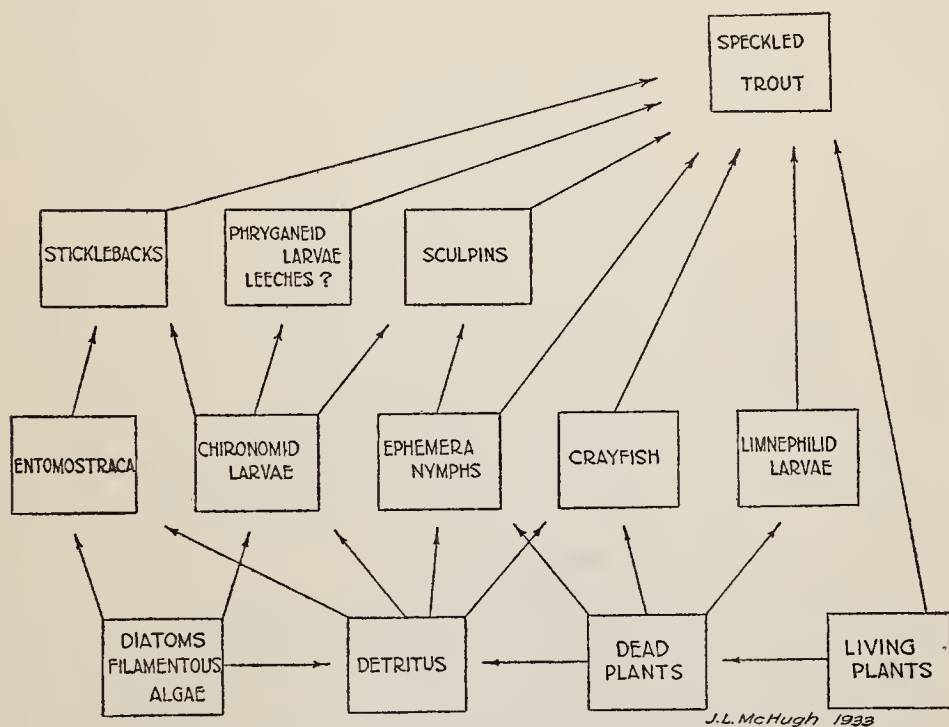


FIGURE 10. Food pyramid of the speckled trout in the Mad river

bare and their fauna exposed, they were joined by land birds such as robins and grackles.

Mammalia

Vespertilionidae. Bats were frequently seen hunting along the stream while mayflies were rising.

Lutreola vison Schreber. Mink were seen on several occasions.

Ondatra zibethica (L.). Tracks and burrows of muskrats were occasional along the stream.

Homo sapiens (L.). Man is probably the principal enemy of the adult speckled trout.

8. Interrelations of the Biota

Briefly the fundamental food cycle in a stream is: animals eat plants. Many animals, however, do not feed directly on plants, but on other animals which feed on plants. In some cases, indeed, many links intervene in a food chain between the basic plant foods and a large carnivorous animal. Complex food pyramids may thus be built up, every one of which has its base in plant materials (figure 10).

Plant material in the stream may conveniently be divided into: (1) larger aquatic plants, including *Chara*; (2) diatoms and filamentous algae; (3) dead fragments of plants, including non-aquatic species, *i.e.* bits of leaves and wood; and (4) finely divided plant material, partially decomposed and unidentifiable, which with a certain amount of dead animal matter, forms the detritus of the bottom. Plankton algae, which are of paramount importance in a lake, are negligible in smaller streams.

Larger aquatic plants are apparently of small importance directly as food for animals. Larvae of *Donacia* are known to feed on stems of some species, but to most stream dwellers they are much more readily available when dead. They are extremely important in providing extensive surfaces for the growth of small algae, especially diatoms. These are eagerly eaten by many animals, including presumably the phytophilous Entomostraca, snails, and some Chironomids. The bottom fauna is mainly nourished by the dead and decomposing remains included in (3) and (4) above. Crayfish, *Ephemera* nymphs, Limnephilid larvae, and probably many Chironomine larvae feed chiefly on debris of this sort, mixed with a few diatoms and occasionally some animal matter. These vegetable-feeders support a considerable number of

carnivores, among which are to be included Phryganeid larvae, Tanypine midges, and probably the abundant leech *Haemopsis plumbeus*.

Almost all of the animals mentioned above are reduced in numbers by fish. Entomostraca are eaten by very young trout and sculpins, and by sticklebacks of all ages. Chironomid larvae are the staple food of all small fish (one to two inches long), being gradually replaced in the larger sculpins and trout by other stream insects, particularly *Ephemera* nymphs. Above this size trout turn to larger invertebrate foods (crayfish and leeches, as well as the bigger insects) and finally begin to take other fish, principally sculpins.

It is easy then to realize that the food supply of any carnivore, such as the speckled trout, is made up of a great many diverse elements which are interrelated in a most complex fashion, though all are finally dependent upon vegetable matter in one state or another.

Figure 10 is the food pyramid of the speckled trout, drawn in an incomplete fashion, which omits many of the less important components. It is typical of what might be compiled for any fish, bird, or animal which plays a part in the life of the stream.

9. Summary of Mad River Investigation

The part of the Mad river included in this study is a slow-flowing trout stream, situated in the highlands of southern Ontario. Its water rises to a fairly high temperature in summer (maximum 24° C.), is alkaline, rich in lime and carbonates, low in carbon dioxide, and contains a good quantity of oxygen at all times. Its bed is of mud or marl-gravel, mostly covered by aquatic plants, and with an average maximum depth of about four feet (1.3 metres). It is rich in invertebrate life, various species of which form several ecological associations, depending upon depth, type of bottom, and presence or absence of weed beds. The

principal fish are sculpins, and speckled trout. The first named is most abundant; it feeds almost exclusively on insects which it obtains from the bottom of the stream. The speckled trout depends on larger insects, crayfish, and sculpins. It sometimes takes insects as they rise to the surface of the river; this is particularly true of one abundant mayfly. Amphibians, birds, and mammals play their part in the life of the river as destroyers of more truly aquatic vertebrates and invertebrates.

SLOW SOFT-WATER TROUT STREAMS

Streams of this type are the soft-water relatives of the Mad river, and occur throughout the pre-Cambrian region, where Laurentian granites and gneiss prevail. They are much commoner than is the Mad river type, and, because usually situated in a forested country, they attain to a much larger size before the temperature rises high enough to place them among the "warm rivers". The most apparent difference between the two is in the type of vegetation: *Chara* is absent from the soft water, while *Brasenia* has not been found in the hard, and *Castalia* is very rare. No extensive faunal studies have been made of the soft-water type; but their fish appear to be more numerous and more varied, including *Notropis cornutus*, *Semotilus atromaculatus*, *Catostomus commersonii*, *Eupomotis gibbosus*, *Perca flavescens*, and in some cases even *Micropterus dolomieu*. Examples of this type of river are found in the quiet reaches of the Ox-tongue, East, and Nipissing, all flowing out of Algonquin park, Ontario.

SWIFT HARD-WATER TROUT STREAMS

Most of the good trout streams of southern Ontario are of this kind; they are very typically represented by the lower part of the Mad river.

The climate, vegetation, and geological features of the Mad river region have already been described (pp. 25 *et seq.*).

The lower Mad falls through the Devil's Glen over lime-encrusted pebbles and stones, dolomitic boulders, and in some places, bed rock. Several water falls five to fifteen feet (1.5 to 4.5 metres) high are found in its course, but for the most part the stream is a succession of rapids. At station 1, where the water samples were taken and most of the collecting done, the bottom was of stones three inches to a foot (8 to 30 cm.) in diameter.

Most of the water of the lower Mad river comes from the reaches above. Along the sides of the glen are numerous rock springs which fall down moss-covered slopes to the river below. In summer they are with rare exceptions colder than the river and reduce its temperature one or two degrees. The volume of flow is subject to large diurnal fluctuations, especially in summer, owing to the opening and closing of the gates at the mill above. For example, on August 13 the flow rose from 7 to 38 cubic feet (0.02 to 1.1 cubic metres) per second in the course of five minutes. Seasonal variation in the volume of flow is much the same as in the upper Mad. Temperatures, pH, and oxygen contents taken throughout the year are recorded in table 16. They present no unusual features, except, perhaps, the uniformly high concentration of dissolved oxygen.

Aquatic vegetation in the lower Mad is confined to cryptogamic plants. Mosses such as *Fontinalis* and *Fissidens* and algae such as *Cladophora* are most conspicuous. There is also a microscopic algal flora which is responsible for the deposition of limy encrustations on the stones of the river bed.

The invertebrate fauna is quite different from that of the upper Mad river; many of the animals show adaptations which enable them to withstand or to avoid the strong current:

Oligochaeta and Hirudinea. Absent.

Crustacea. *Hyalella* absent; *Cambarus bartonii robustus* replaced *C. propinquus*.

TABLE 16. Seasonal variation in water of the lower Mad river

Date	Time	Rate of flow (feet per second)	Volume (cubic feet per second)	Temperature		pH	Oxygen *		
				C.	F.		cc/l	p.p.m.	Per cent. saturation
May 19, 1930.....	11.30 a.m.	5.4	135	7.7	46	7.8	8.2	11.7	103
June 13, 1930.....	4.30 p.m.	3.0	48	18.4	65	7.9	5.4	7.7	88
June 30, 1930.....	2.30 p.m.	2.7	33	19.2	66.5	..	5.7	8.1	95
July 24, 1930.....	4.30 p.m.	..	15	21.0	70	..	..	..	..
August 13, 1930....	3.40 p.m.	1.5	7	18.0	64.5	..	..	..	..
August 13, 1930....	4.30 p.m.	3.2	38	17.6	63.5	..	..	..	..
August 16, 1930....	4.00 p.m.	..	..	19.3	67	..	5.9	8.4	98
September 4, 1930..	2.10 p.m.	1.5	7	17.8	64	7.8	5.6	8.0	89
October 19, 1930....	5.00 p.m.	..	5	1.8	35	7.7	8.8	12.6	98
January 16, 1931....	4.30 p.m.	..	10	0.0	32	7.4	8.5	12.1	90
March 23, 1931.....	11.00 a.m.	3.0	15	0.3	32.5	7.7	8.7	12.4	94
April 19, 1931.....	11.45 a.m.	6.0	300	9.2	48.5	7.6	7.5	10.7	100

*The water was probably saturated with respect to oxygen at all times, because the samples were taken below along rapids and falls. Values less than saturation are low because the water had to be carried some distance before it was analysed, and a small amount of gas would escape from it.

Ephemeroptera. *Ephemera* cf. *simulans* absent, but many stone-clinging Baetids and Heptagenids were found, e.g. *Leptophlebia*, *Baetis*, *Chirotenetes*, *Ephemerella*, *Ecdyurus*, *Heptagenia*, and *Epeorus*.

Odonata. *Boyeria vinosa*.

Plecoptera. Large nymphs of *Perla* and *Acroncuria* are common; smaller forms are *Isoperla*, *Chloroperla*, *Alloperla*, *Nemoura*, and *Leuctra*.

Neuroptera. *Chauliodes*, not uncommon.

Trichoptera. Phryganeids absent; the large Limnephilid *Stenophylax scabripennis* with a case of sticks is found in the pools, but the larvae of *Neophylax* or *Mystrophora* are more typical case-builders, since they use sand grains exclusively. Others are free living, e.g. *Rhyacophila*, or spin nets of various sorts, as *Philopotamus*, *Chimarrha*, *Polycentropus*, and the abundant Hydropsychids. A few small forms build fragile cases of plant material, and live in the shelter of the mosses or algae on the stones, e.g. *Micrasema*? and *Lepidostoma*. Dr. Betten has identified the following imagos, which were taken on this part of the river:

Rhyacophila fuscula. 8.vi.-25.vii.30.

Rhyacophila carolina. 30.vi.30; 6.ix.30.

Rhyacophila sp. 38. 9.vi.30.

Rhyacophila sp.? 18.vi.30.

Mystrophora americana. 23.v.30.

Philopotamus distinctus. 25.vii.30; 13.viii.30;
13.xi.30.

Chimarrha socia. 8.vi.30.

Chimarrha aterrima. 25.vii.30.

Diplectrona modesta. 25.vii.30.

Hydropsyche sp. 30. 15-17.v.30.

Hydropsyche sp. 31. 23.v.-22.vii.30.

Hydropsychodes analis. 23.v.30.

Hydropsychodes sp.? 25.vii.-14.viii.30.

Molanna blenda. 23.vi.30.

Stenophylax scabripennis. 7.ix.30.

Rheophylax submonilifer. 23.v.30.

Atomyia sp. 23.v.30.

Heteroptera. Not found.

Diptera. *Antocha* and a few Chironomids frequent the crevices in the limy encrustation of stones, while *Simulium* larvae are found on bare surfaces. In the weeds live larger crane-flies such as *Dicranota*.

Coleoptera. The only common beetles are *Helmis*, *Psephenus*, and *Dryopus*. The two last are the flat clinging "water-pennies".

Mollusca. Not found here. In moderately swift sections *Sphaerium* may be abundant.

The fish taken at station 1 include only *Salvelinus fontinalis*, *Semotilus atromaculatus*, and *Cottus bairdii*. About a mile down stream *Catostomus commersonii* was observed; it probably cannot ascend the intervening falls. Almost all of the numerous species of stream insects are readily taken by the trout in the stream (table 17). In spring the large *Ephemerella* is often caught just as the sub-imago is emerging from the nymphal skin. *Epeorus humeralis*, several species of *Ecdyurus*, *Leptophlebia*, *Baetis*, *Chirotenetes*, and *Ephemera guttulata* are also found, in greater or lesser abundance. The stoneflies include large *Perla* nymphs, and smaller *Isoperla* and *Leuctra*. Hydropsychidae are preponderant among the caddis flies; most of the pupae are probably of this family. Other forms are Hydroptilidae, *Rhyacophila fuscula*, *Philopotamus*, *Chimarra*, *Polycentropus*, *Helicopsyche*, and Limnephilidae. The lithophilous crane-fly *Antocha* is the principal dipterous larva; other Tipulidae, Chironomidae, and rarely *Simulium* also occur. Though most often taken while still immature, aquatic insects of all families are occasionally captured when in the imagal state.

As the summer advances, the number of aquatic insects taken decreases, and that of terrestrial insects and spiders increases. Cicadellidae, Muscidae, Scarabeidae, and Formicidae are among the families most often represented.

Trout from the Noisy river, Dufferin county, Ontario, a stream very similar to the lower Mad, had taken essentially

TABLE 17. Food of trout in swift hard-water streams

	Mad river May 24 and June 8 1930	Mad river August 16 and September 6 1930	Noisy river July 2 to July 21 1928
Number of specimens examined.....	10	7	7
Average length of trout in inches....	6.6	7.7	5.7
Variation in length.....	5.8-9.5	5.8-9.5	4.5-8.0
Average volume of contents in cubic mm.....	790	270	660
Average number of Nematoda.....	90	5	7
Vegetable matter.....	+	+	—
Crustacea: <i>Cambarus bartonii</i>	12	26	6
Araneida—spiders.....	—	6	2
Aquatic insects			
Ephemeroptera: <i>Epeorus</i>	4	—	2
<i>Ephemerella</i>	21	—	—
<i>Baetis</i>	5	2	+
Others.....	6	3	—
Odonata: Zygoptera.....	—	+	3
Plecoptera.....	2	2	10
Trichoptera: Hydropsychidae...	4	1	—
Other larvae.....	5	2	4
Unidentified pupae	10	8	13
Heteroptera: Corixidae.....	—	2	+
Diptera: Tipulidae.....	6	12	—
Chironomidae.....	2	1	+
Others.....	+	—	+
Coleoptera.....	1	12	1
Terrestrial insects			
Orthoptera.....	1	+	—
Hemiptera.....	—	—	10
Lepidoptera.....	+	12	—
Diptera.....	2	5	5
Coleoptera.....	12	5	15
Hymenoptera.....	1	1	11
Fish: Cyprinidae.....	6	—	—
Trash.....	+	—	—
Total surface food.....	18	30	57
Total submersed food.....	82	70	43

the same foods, though with a greater proportion of land insects (table 17).

The Pine river, also in Dufferin county, is another similar stream, although perhaps somewhat warmer in the places where specimens were obtained. It contains rainbow trout, *Salmo irideus*, as well as the native speckled trout.

TABLE 18. Food of Pine river fishes

	<i>Salvelinus fontinalis</i> June 17	<i>Salmo irideus</i> June 17	<i>Salmo irideus</i> June 17 to 21	<i>Semotilus atromaculatus</i> July 4	<i>Rhinichthys</i> spp. July 4 to 27
Number of specimens examined.....	3	15	4	7	12*
Average length in inches.....	6.6	5.7	9.9	4.1	2.3
Variation in length.....	5.5-7.2	4.9-6.4	7.2-14.5	2.8-6.8	1.6-3.8
Average volume of contents in cubic mm	1340	650	2630	200	60
Average number of Nematoda.....	7	1	2	?	—
Pilamentous algae and diatoms.....	—	15	38	—	—
Polyzoa: <i>Plumatella</i>	—	—	—	—	66
Gastropoda.....	3	—	—	—	+
Crustacea: <i>Cambarus</i>	7	8	7	51	10
Aquatic insects					
Ephemeroptera.....	33	25	1	—	—
Plecoptera.....	—	2	4	—	—
Trichoptera.....	10	14	3	10	13
Heteroptera: Gerridae.....	1	—	—	—	—
Diptera: Chironomidae.....	1	+	+	—	8
Others.....	—	3	2	13	—
Coleoptera.....	—	2	+	—	1
Terrestrial insects					
Hemiptera.....	1	4	—	1	—
Lepidoptera.....	—	+	—	—	+
Diptera.....	—	1	+	—	—
Coleoptera.....	9	4	5	20	+
Hymenoptera.....	34	22	8	4	2
Fish: <i>Colinus</i>	—	—	31	—	—
Total surface food.....	83	65	21	26	2
Total submersed food.....	17	35	79	73	98

*Includes three *R. cataractae* and nine *R. atromaculatus*. The food of the two species was similar.

Other common fish are the horned dace, *Semotilus atromaculatus*, the small dace *Rhinichthys cataractae* and *R. atronasus*, a sculpin *Cottus cognatus*, and the sucker *Catostomus commersonnii*. Some data are at hand concerning the food of the first four, which are summarized in table 18. The diet of the two species of trout was essentially the same at the time these specimens were taken (June), except that the rainbows consumed a considerable quantity of algae, including *Cladophora*, *Mougeotia*, and diatoms. Metzelaar (1928) has found large quantities of algae in rainbow trout from Michigan. Crayfish formed half of the food of the horned dace, which are thus competitors of the larger trout. The long-nosed and black-nosed dace (*Rhinichthys*) consume *Plumatella*, an organism which the other fish do not touch.

SWIFT SOFT-WATER TROUT STREAMS

The Oxtongue river rises from numerous lakes and streams in the south-western corner of Algonquin park, district of Nipissing, Ontario. It is first to be recognized immediately below the dam of Tea lake, which section is referred to here as the upper Oxtongue. Fifteen or twenty miles (about 30 km.) below this point it enters a lake having the same name—an elongate body of water two square miles (5 square km.) in extent. Immediately below this lake the lower Oxtongue begins, in which section most of the studies were made. Its location is longitude 78° 58' W. and latitude 45° 18' N. Five miles (8 km.) below this point it empties into the lake of Bays and finally into Georgian bay by way of the Muskoka river.

Immediately below Oxtongue lake, the river flows down through a rather narrow valley in a long series of rapids and pools. The basal igneous rock of the region, nowhere deeply covered, is exposed along the sides of the gorge, and in places forms the bed of the stream. The slopes on either side are wooded with coniferous and deciduous trees, among which yellow birch, red maple, and poplars predominate.

The rapid studied is about 50 feet (16 metres) wide and

up to four feet (1.3 metres) in depth, averaging 28 inches (70 cm.). The current is fast, and volume of flow large: over 300 cubic feet (8.5 cubic metres) per second late in May. The water is dark brown in colour, and rises to a rather high temperature—about 23°C.—on hot summer days, but is, of course, well oxygenated. It is “soft”, *i.e.* deficient in lime and magnesium, as shown by an analysis made at 1.00 p.m. on May 30, 1930: free carbon dioxide 1.3 parts per million, acid carbonate (HCO_3) 6, hardness 40, the last two expressed as parts per million of CaCO_3 . Table 19 summarizes most of the available information concerning water conditions in the Oxtongue river.

TABLE 19. Water characteristics of the lower Oxtongue river

Date 1930	Time	Rate of flow (ft. per sec.)	Vol. (cu. ft. per sec.)	Temperature		pH.	Oxygen		
				C.	F.		cc/l.	p.p.m.	Per cent. sat.
May 30	1.00 p.m.	4.5	315	13.2	56.0	..	6.5	9.3	93
July 18	6.00 p.m.	..	..	22.4	72.5	6.2	5.85	8.3	102
Sept. 20	4.45 p.m.	3.0	135	17.6	63.5	..	5.9	8.4	93

The only vegetation noticed in the rapids consisted of rock-clinging algae. *Cladophora* was very abundant in July, and in September many of the stones were covered with *Zygnema* and *Mougeotia*.

The following list of invertebrates is based upon collections made in May, July, and September, 1930.

Porifera

Spongilla. Rare.

Polyzoa

Plumatella. Rare.

Turbellaria

Planaria. Rare.

Hirudinea

A small white leech was distributed occasionally and rather uniformly, in sand under the stones.

Crustacea

Cambarus bartonii bartonii. Rare; occasional in the less rapid parts.

Ephemeroptera

Leptophlebia mollis. Frequent.

Ephemerella deficiens. Occasional.

Ephemerella sp. Occasional.

Baetis. Frequent.

Epeorus humeralis. Frequent.

Heptagenia hebe. Occasional.

H. pullus. Occasional.

Ecdyonurus canadensis. Rare.

Ecdyonurus sp. (*fusca* group). Occasional.

Odonata

Ophiogomphus rupinsulensis. Imagos taken on upper Oxtongue.

Boyeria vinosa. Imagos taken on upper Oxtongue.

Plecoptera

Perla. Large nymphs which are to be referred to two species of this genus or of *Acroneuria* were occasionally collected.

Isoperla. Rare.

Alloperla. Frequent.

Trichoptera

Hydroptilidae. Abundant.

Rhyacophila fuscula. Occasional.

Hydropsychidae. Frequent, at least two species were represented. In the upper Oxtongue, August 16, 1929, they were abundant.

Polycentropus ? Occasional.

Chimarra. Occasional (two species).

Lepidostoma. Rare.

Limnephilidae. Occasional.

Diptera

Simulium. Extremely abundant. On May 30, the larvae were found covering every stone as closely as did the *Cladophora* later in the summer. As many as 800 individuals were taken from four

square inches (26 square cm.) and a conservative estimate for the whole rapid is 5,000 per square foot (54,000 per square metre). Pupae were frequent, being anchored to the downstream side of stones. Most of these larvae transform and emerge in June; a search on July 16 revealed only three specimens among the stones where they were formerly so numerous.

Tanypinae. Rare.

Chironominae. Occasional. Chironomid larvae are less common in soft-water streams, perhaps because of the absence of any limy encrustation on the stones, in the fissures of which they are wont to lie. The Tipulid *Antocha*, which has a similar habit, was absent.

Bibiocephala. Occasional.

Coleoptera

Helmis. Occasional.

Psephenus. Rare.

The invertebrate fauna of these soft-water trout streams is very similar to that of hard-water rivers having a similar temperature; many of the same species of insects are found in both situations. The characteristic feature of the soft-water association is its enormous population of *Simulium* larvae, beside which the numbers found in hard waters are quite insignificant. The adult females of this insect are well known as the biting black-flies which at times make life unbearable in the northern woods. Another dipterous larva which appears to prefer soft waters is of the Blepharocerid genus *Bibiocephala*.

In other brown-water streams the relative abundance of the various organisms is somewhat different from that observed in the Oxtongue. For example, in one river a great number of sponges and many colonies of *Cristatella* were found; in another *Plumatella* occurred frequently; in the East river, a more northerly branch of the Muskoka, there were found Hydropsychid larvae quite different from the species common in the Oxtongue. But the present

survey is far from complete, and these species may abound in parts of the last-named river.

An incomplete list of fish occurring in the river is: *Salvelinus fontinalis*, *Catostomus commersonnii*, *Semotilus atromaculatus*, *Eupomotis gibbosus*, and *Micropterus dolomieu*. Specimens of the two game species, taken in the upper Oxtongue, August 16-24, 1929, were examined for stomach contents, and the results set forth in table 20. Difference in habitat of the two species is reflected in food differences. The trout, taken in the swift water, had eaten insects characteristic of the lotic association: Simulid and Hydropsychid larvae; the bass, in more quiet backwaters, must be content with imaginal caddis flies, a few other insects, and small fish. Large bass are rarely found near the rapids; they prefer the slow deep reaches of the river, which belong in the "slow soft-water trout stream" division of this classification. Nothing is known of the relation of trout to bass in those surroundings.

TABLE 20. Food of game fish in the Oxtongue river, August 16-24, 1929

	Trout <i>S. fontinalis</i>	Bass * <i>M. dolomieu</i>
Number of specimens examined.....	19	6
Average length of fish in inches.....	6.3	5.4
Variation in length.....	5.1-7.3	4.7-6.0
Average volume of contents in cubic mm.....	490	130
Average number of Nematoda.....	0	+
Vegetable matter.....	+	—
Aquatic insects		
Ephemeroptera.....	+	—
Trichoptera: Imagos and pupae.....	15	50
Larvae of Hydropsychidae.....	18	—
Heteroptera: Gerridae.....	+	—
Diptera: Chironomidae.....	5	8
Simuliidae.....	61	6
Others.....	+	12
Terrestrial insects		
Hemiptera.....	+	—
Diptera.....	+	—
Coleoptera.....	+	—
Fish.....	—	24

*The bass stomachs were examined by Mr. A. L. Tester.

From the East river, which is close to and very like the Oxtongue, and from the Nipissing, a similar stream in the northern part of Algonquin park, the author has been able to secure specimens of other fish associated with the speckled trout in these brown water rivers. Table 21 shows the food of the chub, shiners, perch, and sunfish in the two rivers, and of trout from these and two other rivers of the Algonquin park region.

From a study of tables 20 and 21 it will be seen that none of the "forage" fish, with the exception of the horned dace, is a serious competitor of the game fish in these rivers. The shiners and sunfish take algae and Bryozoa which trout do not touch; the two perch examined had also favoured Bryozoa; two small suckers confined themselves to Entomostraca and midge larvae, which they had probably taken in quiet water. The horned dace, both in these streams and in others, show a preference for crayfish, thus coming into direct competition with the bass and with the larger trout. They are themselves often eaten by the trout, along with shiners (*Notropis cornutus*) and suckers (*Catostomus commersonnii*).

Figure 11 gives an idea of the food relationship of vertebrates to invertebrates in these streams. Bass have been omitted, because they occurred in only two of the streams examined, and in any case are more usually found in the slower sections.

Soft-water trout streams commonly attain to a much larger size than do the trout streams of calcareous regions. From this we might conclude that trout are able to tolerate higher temperatures when in water poor in lime and with a low pH. A more probable explanation is that, since in Ontario to-day soft-water streams almost always flow through a completely forested watershed, they are not as easily warmed up, and consequently reach large proportions before their temperature rises to the critical point above which trout are no longer able to survive. The information necessary for a decision between these two alternatives is not yet available.

WARM RIVERS

The transition from the trout stream to the warm river is a fairly abrupt one, and is characterized by an increase in the number of species of all kinds of organisms: plants, invertebrates, and vertebrates; and by the disappearance of some of the types characteristic of the colder waters. Among the latter is the speckled trout.

The Credit river illustrates these changes well. In some of its upper reaches it approximates closely to the swift

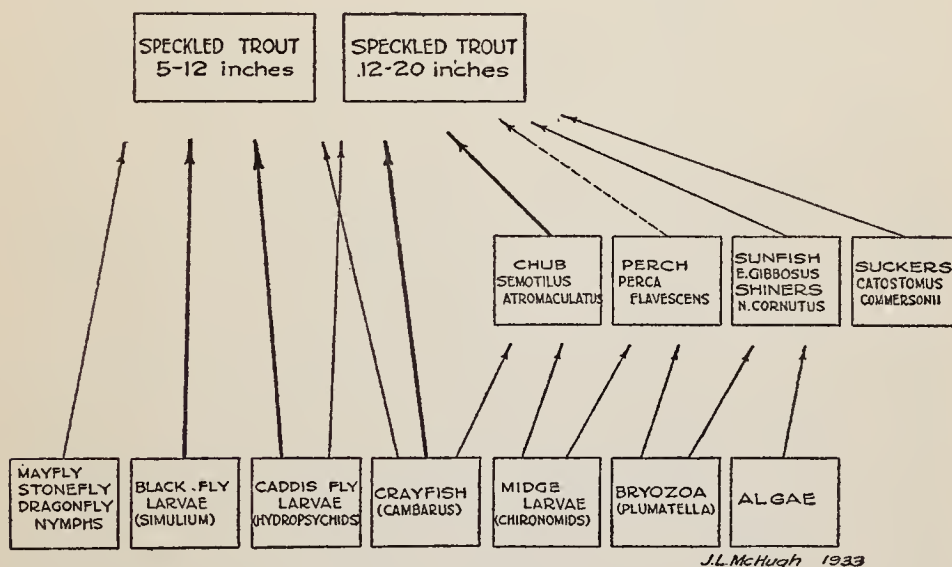


FIGURE 11. Biotic relationships in swift soft-water trout streams

trout stream type, of which the lower Mad river was our example. A mile below Credit Forks, where it is still a fair trout stream, *Semotilus atromaculatus*, the two species of *Rhinichthys*, and *Catostomus commersonii* were abundant; a *Cottus* and two *Catnotus flabellaris* were taken. A few miles below this point trout no longer occur commonly, and other stream fish appear and become abundant. Plants, too, increase in variety, including in the rapid water *Potamogeton pectinatus*, *P. heterophyllus*?, and in the quiet stretches *P. natans*, *P. americanus*, *P. richardsonii*, *P. perfoliatus*,

TABLE 21. Food of fish in swift brown-water streams

	Speckled trout <i>S. fontinalis</i>			Sucker <i>C. commersonii</i>	Horned dace <i>S. alromaculatus</i>	Shiner <i>N. cornutus</i>	Sunfish <i>E. gibbosus</i>	Perch <i>P. flavescens</i>
Number of specimens from East river.....	0	0	3	0	2	8	0	1
Number of specimens from Nipissing river...	0	0	7	0	5	10	6	1
Number of specimens from Petawawa river...	2	0	0	2	2	2	0	0
Number of specimens from Madawaska river	3	5	0	0	0	0	0	0
Average length in inches.....	17.3	14.6	7.8	5.6	5.8	5.7	4.3	4.8
Variation in length.....	16-18	13.5-15	6.0-9.5	4.8-6.5	4.5-8.8	4.5-6.5	3.8-4.9	4.2-5.5
Average volume of contents in cubic mm.....	35000	4400	340	250	300	400	220	50
Filamentous algae.....	—	—	—	—	3	39	73	—
Diatoms.....	—	—	—	6	—	—	—	—
Bryozoa: <i>Plumatella</i>	—	—	—	—	—	54	15	90
Gastropoda: <i>Ferissia</i>	—	—	—	—	—	—	12	—
Crustacea: Cladocera.....	—	—	—	18	—	—	—	—
Copepoda.....	—	—	—	14	—	—	—	—
Ostracoda.....	—	—	—	12	—	—	—	—
<i>Cambarus bartonii</i>	10	18	—	—	97	—	—	—
Aquatic insects	—	—	—	—	—	—	—	—
Ephemeroptera.....	—	+	3	—	—	2	—	—
Odonata.....	+	—	—	—	—	—	—	—
Plecoptera.....	+	3	9	—	—	—	—	—
Megaloptera: <i>Chauliodes</i>	+	—	—	—	—	—	—	—
Trichoptera: Hydropsychidae.....	+	51	9	—	—	—	—	—
Unidentified.....	+	4	13	—	—	—	—	—
Larval cases.....	—	6	—	—	—	—	—	—
Heteroptera: <i>Rhagovelia</i>	—	—	3	—	—	—	—	—
Diptera: Simuliidae.....	+	1	20	—	—	+	—	10
Chironomidae.....	+	+	5	50	—	—	—	—
Others.....	—	—	1	—	—	—	—	—
Coleoptera: <i>Psephenus</i>	—	—	+	—	—	—	—	—
Terrestrial insects.....	—	—	—	—	—	—	—	—
Fish: (dace, shiners, suckers).....	82	15	35	—	—	—	—	—
Frogs.....	3	—	—	—	—	—	—	—
Total surface food.....	0	0	2	0	0	0	0	0
Total bottom food.....	100	100	98	100	100	100	100	100

P. crispus, *P. zosterifolius*, *Elodea canadensis*, *Vallisneria spiralis*, *Heteranthera dubia*, *Ceratophyllum demersum*, *Nymphaea advena*, *Myriophyllum* spp., and a great variety of upright emergent species. Studies of the fish fauna were made near the mouth of the river by Dymond *et al.* (1929). They record from a stony bottom: *Catostomus commersonnii*, *Hypentelium nigricans*, *Nocomis micropogon*, *Rhinichthys cataractae*, *Semotilus atromaculatus*, *Notropis whippelii*, *N. rubellus*, *N. cornutus*, *Hyborhynchus notatus*, *Noturus flavus*, *Esox lucius*, *Percina caprodes*, *Boleosoma nigrum*, *Poeciliichthys coeruleus*, *Catnotus flabellaris*, *Microperca punctulata*, and *Micropterus dolomieu*; and from quiet lagoons with muddy bottom and abundant vegetation: *Catostomus commersonnii*, *Moxostoma rubreque*, *M. aureolum*, *Cyprinus carpio*, *Notropis deliciosus*, *N. cornutus*, *Notemigonus crysoleucas*, *Hyborhynchus notatus*, *Ameiurus nebulosus*, *Noturus flavus*, *Esox lucius*, *Anguilla rostrata*, *Micropterus dolomieu*, *Helioperca incisor*, *Pomoxis sparoides*, and *Ambloplites rupestris*.

The precise factor or factors which limit the occurrence of speckled trout in these warm rivers is not fully understood; temperature, hydrogen-ion concentration, oxygen supply, turbidity, paucity of spawning beds, competition of such fish as the creek chub, and active destruction by such fish as the black bass and pike have all been suggested. Creaser and Brown (1927) have demonstrated clearly the high negative correlation which exists between water temperature and the occurrence of trout, which correlation, of course, does not at once establish a direct causal connection. The view of Breder (1927), that the effect of temperature is made apparent only through decreased oxygen content, is not substantiated by my observations, nor by the experiments of Gutsell (1929). It has already been vigorously attacked by Creaser in a later paper (1930). The last author has apparently eliminated the ordinary physico-chemical water characteristics, other than temperature, as possible direct causative agents in determining the "voluntary toleration limit" of the species. There remain the biological charac-

teristics, notably the presence of enemy or competitor fishes, to be considered before temperature can finally be accepted as the immediate limiting factor.

Creaser (1930) says: "The maximum temperature for natural self-sustaining brook-trout waters is now rather well established as about 19° C. or 66° F. When the temperature goes higher than this maximum for any considerable period the brook-trout soon disappear." He considers 19° C. the voluntary toleration limit, rather than the "lethal limit", which Embury (1922) found may be as high as 28° C. How long a "considerable period" may be is, of course, debatable, but if a stream rises above 19° C. for from two to six hours on all the hot clear days of midsummer, its fish must be fairly well adapted to such temperatures. The Mad river, an excellent trout stream, rose above 19° C. on many occasions in 1930, commonly remaining so for a period of 12 hours, and on one occasion for more than 36 hours (*cf.* figure 4). The temperatures of a number of Ontario streams, taken on a clear day in summer, are shown below. Many of these are obviously a degree or more below the probable maximum for the day, and there is no assurance that any (except those for the Mad river) represent the seasonal maximum.

It is clear that many good Ontario trout streams commonly attain at least to 21 or 22° C. in summer, and probably remain at this point for several hours each bright day. (The curve of water temperature is quite flat near its maximum.) The limit of 24° C. maximum temperature, selected from these data and used in the classification to separate "warm rivers" from "trout streams", may even prove to be too low when additional data are available from the brown-water streams of the north. In any case it cannot claim great exactitude when applied to individual examples. There is a suggestion that the presence or absence of other fishes is of first-rate importance in border-line cases; for example, would the Mad river retain its present large trout population if bass, suckers, *etc.*, had access to its waters? Again, trout caught near the lower limit of their stream habitat are commonly of large size; whatever factor denies the species

a more extended range must evidently bear most heavily upon the younger specimens.

We may agree with Creaser and Brown that "the temperature difference between a very good and a very poor trout stream is very slight" not more than about 2° C. But the evidence from these streams is that the voluntary toleration limit of speckled trout is close to 24 °C. (75° F.),

County or District	River	Date	Time	Temperature C.	Occurrence of speckled trout
Muskoka..	Upper Oxtongue..	August 16, 1929	3.15 p.m.	18.8	Abundant
Dufferin...	Credit near Inglewood.....	August 30, 1928	4.40 p.m.	20.1	Occasional
Ontario...	Siloam outlet	August 15, 1928	2.40 p.m.	20.8	Present
Simcoe....	Lower Mad.....	July 24, 1930..	4.30 p.m.	21.0	Frequent
Grey.....	Styx.....	July 8, 1930..	5.15 p.m.	21.0	Frequent
Dufferin...	Noisy.....	July 2, 1928..	4.05 p.m.	21.3	Frequent
Bruce.....	Sauble.....	July 11, 1930..	6.00 p.m.	21.5	Rare
Grey.....	Upper Mad.....	July 6, 1928..	3.00 p.m.	22.3	Abundant
Dufferin...	Boyne.....	July 17, 1928..	3.30 p.m.	22.4	Frequent
Muskoka..	Lower Oxtongue..	July 18, 1930..	6.00 p.m.	22.4	Occasional
Muskoka..	East.....	July 19, 1930..	6.00 p.m.	22.8	Frequent
Dufferin...	Pine.....	July 4, 1928..	3.00 p.m.	22.9	Frequent
Grey.....	Mad.....	July 25, 1930..	5.00 p.m.	23.1*	Abundant
Grey.....	Mad.....	July 27, 1930..	6.15 p.m.	23.4*	Abundant
Grey.....	Mad.....	July 28, 1930..	6.00 p.m.	23.9*	Abundant
Bruce.....	Lucknow creek...	July 10, 1930..	5.00 p.m.	23.8	None
Bruce.....	Lower Saugeen...	July 10, 1930..	6.00 p.m.	24.8	None
Peel.....	Credit at mouth..	July 13, 1927..	4.40 p.m.	25.5	None

*Recording thermometer maximum for the day.

rather than 19° C. (66° F.). In fact, if a maximum of 19° C. were to be taken as the limiting temperature, many of the best trout-fishing streams in Ontario would be excluded.

GENERAL SUMMARY

In the past aquatic biology has been largely concerned with the investigation of lakes. The conditions which obtain in fluviatile waters are more varied, but equally susceptible to systematic ecological treatment. The detailed examination of one type of stream and a similar though

less comprehensive survey of other types serve as an introduction to such a study of Ontario waters.

The characteristics which distinguish one river from another have to do with its size, the physical and chemical properties of its water, the texture of its bottom, and the nature and abundance of its flora and fauna, all of which are correlated in greater or lesser degree. In formulating a classification of Ontario streams, volume of flow and temperature have been used for the primary groupings, current speed and bottom texture to separate the secondary classes, and quantity of dissolved solids in the water for the final subdivision.

Small streams or "creeks", are to be divided on a temperature basis into spring creeks and drainage creeks. The colder types at least are marked off into distinct classes according as their bottom is of stones, sand, mud, or humus. With each sort of bottom is associated a peculiar fauna, which is greatest in quantity over rich humus, and almost nil in barren sand beds. In soft water, speckled trout are typically the only fish in such streams; in hard waters the sculpin (*Cottus* sp.) and stickleback (*Eucalia inconstans*) are often present in small numbers.

Larger streams are also to be separated on account of their temperature, the dividing point—a summer maximum of 24° C.—being near the limit for the frequent occurrence of speckled trout. In the cooler type, trout are dominant, having associated with them the horned, black-nosed, and long-nosed dace, sculpin, sometimes the common sucker, and in soft waters the chub *Couesius*. In the warm rivers trout do not occur, the important piscivorous fishes being pike and Centrarchids, which are accompanied by a great variety of minnows, suckers, catfish, darters, etc.

The Mad river is one of the slow mud-bottomed trout streams, and is the one which has received most detailed attention in this paper. Most good Ontario trout streams are swift and stony, and, of course, have a fauna quite distinct from the slower rivers. Although soft waters are in most respects very similar to hard waters as regards

fauna and flora, a few organisms, *e.g.* *Chara* and *Simulium*, appear to have their distribution or numbers controlled by the carbonate content of the water or some associated factor.

Because of the value of their game fish, the extension of our knowledge of the biology of the various classes of streams is of prime economic importance. Scientifically, such information will make our understanding of river communities more nearly comparable to what is now known of lakes.

ACKNOWLEDGEMENTS

The author is indebted to many owners of streams for permission to work on their properties, especially Messrs. Gregory Clark and Willis Neff. Field work has been facilitated by the active co-operation of Dr. F. P. Ide. The value of the study has been greatly enhanced by the work of the various specialists who have identified many of the organisms collected. Finally, the author wishes to acknowledge the advice and assistance of the late Dr. B. A. Bensley, Dr. E. M. Walker, Professor J. R. Dymond, Professor W. J. K. Harkness, and other members of the staff of the University of Toronto.

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